Siphons and Circuits
Study Guide and Discussion Questions
Teacher's Guide

Goal:
Students will be able to visualize the nature of electricity by comparing it to water flow.

Objectives:
Students will answer questions on the relationships between power, pressure or force, and flow or current after observing the difference between water flow in two different sizes of siphon tubing

Time: 50 minutes

Materials needed for each group or class:
- two transparent jugs or buckets of at least 1 gallon capacity
- two transparent siphon tubes of different diameters
- 1 or more gallons water

Materials needed for each student:
- copy of the Study Guide and Discussion Questions
- copy of Figure 4-1 and Figure 4-2

Procedure:

1) Teacher-led discussion. Write an answer for each of these questions. (10 minutes)

What is electricity***?*** *(Write student ideas on a board or chart paper. Then write "Electricity = Energy" at the top of the list and explain that if you need to describe electricity in a single word, this is the word to use: electricity is a form of energy.)*
What are some other forms of energy? *(light, heat, motion)*

Can you see electricity? Smell it? Hear it? Feel it? *(All answers are NO, although you certainly feel something when electricity causes your muscles to contract, and when electricity burns your body)*
So how do we know it's there? What clues do we have? *(Take ideas.)*

Note: Because electricity cannot be seen or heard, scientists puzzled over its nature for years. They had clues it was there because they identified some strange forces in nature.

What clues did they have, 400 years ago, before the age of electronics?
(lightning, magnetism, static charge)

Note: We now know that electricity is the movement of subatomic particles called electrons, but that was discovered just recently in the 1900s. Before then, scientists imagined electricity to be some invisible fluid, like water. Although that didn't turn out to be exactly correct, thinking about water and how it moves is still a good way to "image" or "imagine" electricity.

2) Teacher-led demonstration or small group activity on siphons. Write an answer to each of the questions as you do the activity.
(Explain that you are going to show them how a siphon works.)

---Place a bucket half full of water on a table, with one end of each siphon tube in the water.
---Put the other bucket on the floor.
---Start each siphon going by sucking hard on the end of it (You may get a mouthful of water.) The end you are sucking on must be BELOW the other end in order to get the siphon going.
---Raise the end of one of the siphons slightly above the level of the bucket on the table.

What do you notice now? *(The flow will stop.)*
---Lower the end again.

What do you notice now? *(The flow will begin again.)*
(Stop the siphons and have the students answer the questions. Then debrief as a class.)

Is there energy here? Is something moving? *(We know there is energy present because water is moving. Energy is required for movement.)*

Where does the energy come from? *(Energy must come from somewhere. It never appears out of nowhere. In this case, there is potential energy--the weight of the water stored in the top bucket. You stored energy in the bucket of water when you "worked" to lift it to that height.)*

What force is acting on the water to make it flow? *(Earth's gravity)*

Why did the water stop flowing when the end of the siphon was raised?
(The pressure from the weight of the water is reduced.)

What is different about the two siphon tubes and how does this difference affect the flow of water? *(One tube is smaller than the other. The water flow is slower in the smaller tube.)*

Can you use this water do work? *(Yes, you can use the energy to move water from one place to another or to turn a small paddle wheel.)*

3) Diagrams of siphon and of electrical circuit (See Figure 4-1 and 4-2).

---Study the diagram of the siphon in Figure 4-1.
---Notice that the force in the system is the pressure of the water due to gravity, the current is the amount of water flowing through the siphon each second and the power of the water is how much work the water can do each second as it shoots out of the tube below.

Note: The equation that expresses the relationship between these three variables:
POWER = PRESSURE X FLOW or POWER = FORCE X CURRENT

---Discuss and write an answer for each of these questions:

In the activity that we did, can the force be changed? *(The force is due to the strength of* *gravity, which is a constant, at least in your classroom, and the amount of water that the gravity is "acting on". You can increase the amount of water, or the height of the water in the bucket.)*

How does increasing the force change the power? *(increases it)*

In the experiment we did, can the current be changed? *(Yes, a wider siphon tube gives more current.)*

How does increasing the current change the power? (*It increases it. Explain that the equation POWER = FORCE X CURRENT is also true for electrical circuits. In this case the electrical "force" is called the Voltage. And the electrical current, or what is "flowing" through the circuit is not water but electrons.*)

--- Study the diagram of an electrical circuit in Figure 4-2.

In this scenario, can the force be changed? *(Yes, use a higher voltage battery)*

In this scenario, can the current be changed? *(Yes, use a different kind of "resistance" light bulb or electrical load).*

If the current increases, what happens to the power? *(It increases proportional to the current.)*

How are different "sizes" of light bulbs identified? *(Light bulbs are identified by their voltage rating and by the power or watts they use).*

When might you want more power in this system, and when might you want less? (bright light vs. dim light.)

Why would you want to use less energy when possible? *(to save fossil fuels, to save money)*

How is electrical flow through wires similar to the flow of water through pipes? How is it different? *(Take ideas.)*

To learn more:

Timeline: history of electricity
http://maxwell.byu.edu/~spencerr/phys442/history.pdf

Diagram of electric circuit
http://www.ndt-ed.org/EducationResources/HighSchool/Electricity/circuitdiagrams.htm

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Adapted by Gayle Simmons of Wentz Electric from the New Mexico Solar Energy Association, *Schools with Sol Supplemental Reading, Exercises and Lesson Plans:* New Mexico Energy, Minerals, and Natural Resources Department: March 2007, pages 8-10

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What are some other forms of energy?

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What do you notice now?

Lower the end again. What do you notice now?

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Where does the energy come from?

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Note: The equation that expresses the relationship between these three variables:
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---Discuss and write an answer for each of these questions:

In the activity that we did, can the force be changed?

How does increasing the force change the power?

In the experiment we did, can the current be changed?

How does increasing the current change the power?

--- Study the diagram of an electrical circuit in Figure 4-2.

In this scenario, can the force be changed?

In this scenario, can the current be changed?

If the current increases, what happens to the power?

How are different "sizes" of light bulbs identified?

When might you want more power in this system, and when might you want less?

Why would you want to use less energy when possible?

How is electrical flow through wires similar to the flow of water through pipes? How is it different?

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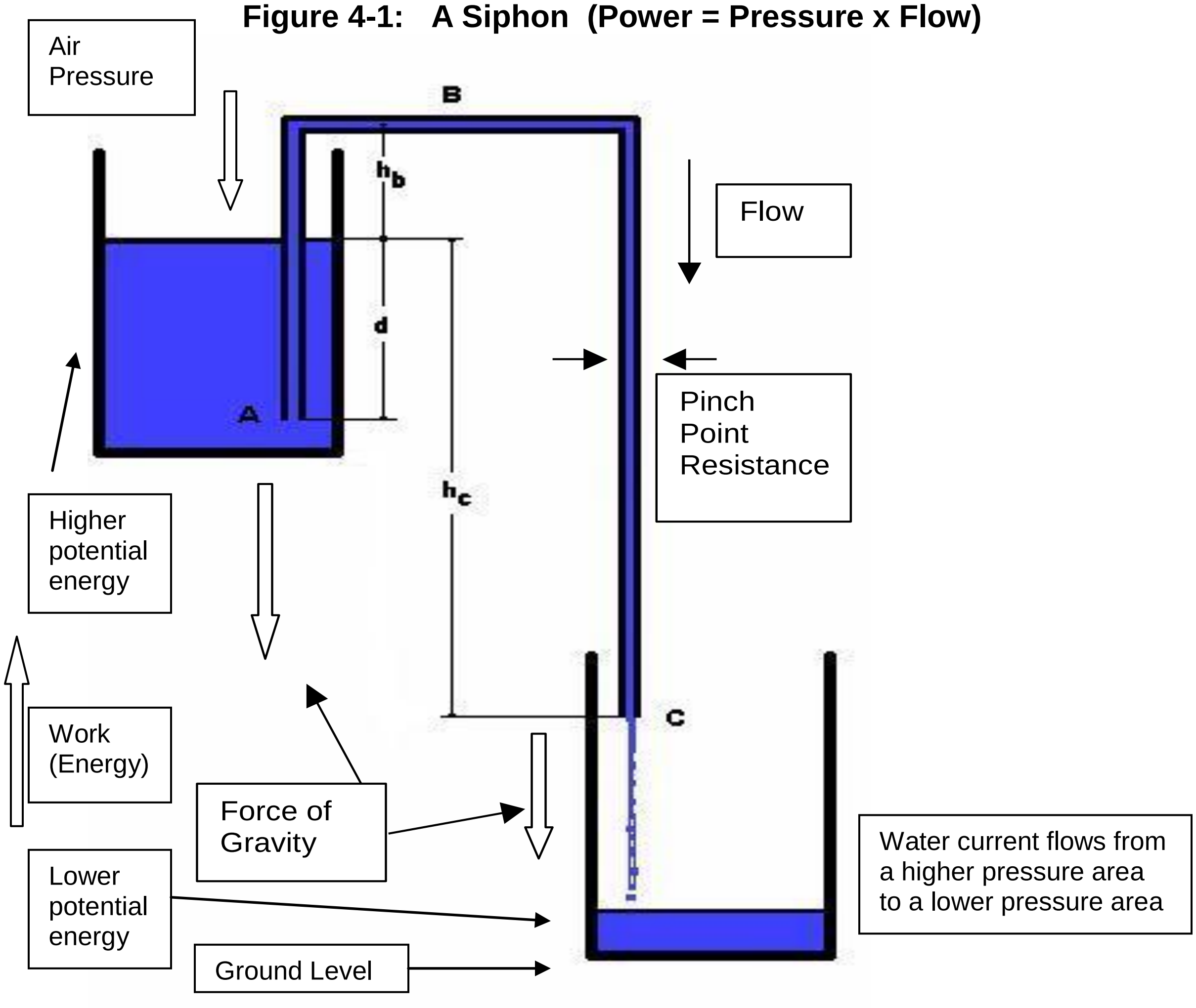
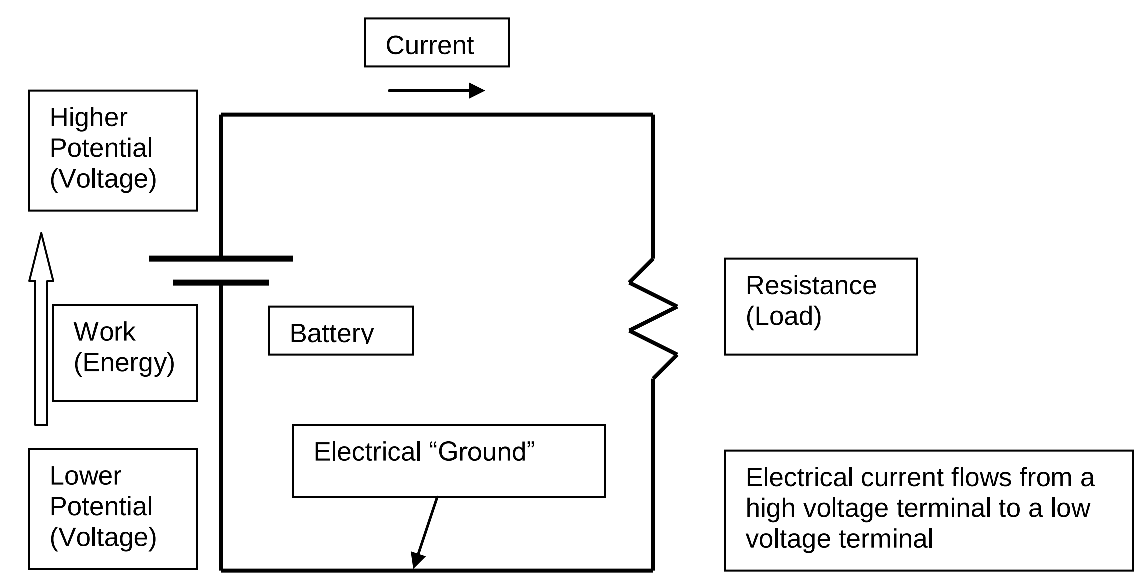
Figure 4-1: A Siphon (Power = Pressure x Flow)



(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

Figure 4-2: An Electrical Circuit (Power = Voltage x Current)



Pumps and Batteries
Study guide and Discussion Questions
Teacher's Guide

Goal:
Students will be able to visualize the movement of energy through two different systems (a water circuit and an electric circuit) to understand Ohm's law.

Objective:
Students will study diagrams of water circuits and electric circuits and write answers to questions that will lead them to a general understanding of Ohm's law.

Materials:
One copy of Figures 5-1, 5-2, 5-3, and this page per student.

Procedure:
Study the diagrams and captions in Figures 5-1, 5-2, and 5-3. Write answers to the following questions based on what you learn.

1. When you "turn on" a faucet at home or at school, water flows out. Why?
   (The water pressure in the pipes forces the water to flow to a lower pressure area)

2. What is creating that water pressure? Have you ever seen a "water tower"? What does a water tower do?
   *(A water tower stores lots of water at a fixed height **above** the houses or schools that want to use the water)*

3. If a water tower is storing water high above the town, does that water have any "potential energy"? Why?
   (Water is "heavy" because of the attraction of gravity. Water will flow "downhill" if you give it a chance. The weight of that water creates the water pressure.)

4. Many cities don't build high water towers anymore. How do those cities create "water pressure" in their water pipes so that water will flow out when a faucet is opened? (They use pumps.)

Note: *A **pump** is a machine that is designed to create a difference in water pressure between its input and its output. A standard pump has a low input water pressure and a high output water pressure. That difference in pressure can be used to "force" the water to flow.*

5. It takes energy to create a pressure difference, and to lift and move water. Where does a pump get the energy to do this work?
   (A manual pump gets its energy from the person operating it. These days most water pumps run on electricity, that is, they "transform" electrical energy into water pressure, the form of energy needed to make water flow.)

Note: *A difference in water pressure, created by a pump, is used to force water to flow. A difference in voltage or "electrical potential", created by a battery, is used to force electrical current to flow.*

Note: *A battery is a device that is designed to create a difference in voltage between its two connections or "terminals". A standard battery has a "negative" or low voltage* *terminal and a "positive" or high voltage terminal. That difference in voltage can be used to "force" electrons to flow.*

6. It takes energy to create a voltage difference, and to force electrons to flow. Where does a battery get the energy to do this work?
   (A battery "stores" energy in a chemical form. When a battery is used in a circuit, a chemical reaction "transforms" the stored chemical energy into electrical energy.)

Adapted by Gayle Simmons of Wentz Electric from New Mexico Solar Energy Association, *Schools with Sol Supplemental Reading, Exercises and Lesson Plans:* New Mexico Energy, Minerals, and Natural Resources Department: March 2007, pages 11-13

Pumps and Batteries
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Objective:
Students will study diagrams of water circuits and electric circuits and write answers to questions that will lead them to a general understanding of Ohm's law.

Materials:
One copy of Figures 5-1, 5-2, 5-3, and this page per student.

Procedure:
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2. What is creating that water pressure? Have you ever seen a "water tower"? What does a water tower do?

3. If a water tower is storing water high above the town, does that water have any "potential energy"? Why?

4. Many cities don't build high water towers anymore. How do those cities create "water pressure" in their water pipes so that water will flow out when a faucet is opened?

Note: *A* ***pump*** *is* a *machine that is designed to create* a *difference in water pressure between its input and its output. A standard pump has* a *low input water pressure and* a *high output water pressure. That difference in pressure can be used to "force" the water to flow.*

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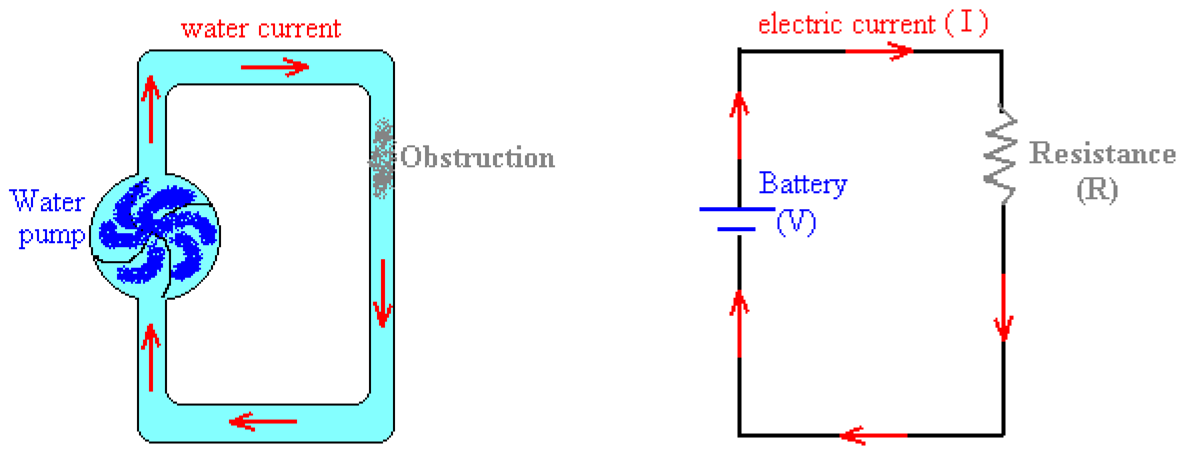
New Mexico Solar Energy Association, *Schools with Sol Supplemental Reading, Exercises and Lesson Plans:* New Mexico Energy, Minerals, and Natural Resources Department: March 2007 pages 11-13

Figure 5-1: Water Circuits and DC Circuits



Water Circuit

Electrical Circuit

In a **water circuit**, the force or pressure needed to move the water is supplied by a pump.

- The rate of water flow depends on the pressure difference and the resistance to the flow (e.g. due to some valve or obstruction in the circuit pipe).
- For a given resistance, the greater the pressure difference, the greater the water flow.
- For a given pressure difference, the greater the resistance, the less the water flow.

Flow = Pressure Difference / Resistance

In a **DC electrical circuit**, the "electro-motive force" or voltage needed to move the electrons is supplied by a battery or a "DC power supply".

- The rate of electron flow (charge flow), or current, depends on the voltage and the electrical resistance or "load".
- For a given resistance, the greater the voltage, the greater the current flow.
- For a given voltage difference, the greater the resistance, the less the current flow.

Current = Voltage Difference / Resistance (or I = V/R)

The simple equation: Current = Voltage Difference / Resistance (I = V / R)
is one of the forms of "Ohm's Law".
There are two other forms of this equation. What are they?
(V = I X R and R = V / I)
The "original" form of Ohm's Law is the last equation, R = V / I .
Georg Ohm formulated "Ohm's Law" in 1827. (no, I didn't misspell his name)
Do you think Herr Ohm understood water flow?
The "Ohm" was adopted as the standard name of the unit used to measure electrical resistance. That's why the term Ohm is always capitalized.

If "V" if used to represent Voltage (measured in Volts), and "R" is used to represent Resistance (measured in Ohms), why do scientists and engineers use "I" to represent Current (measured in Amperes or Amps)???? Job Security!!!

Adapted from New Mexico Solar Energy Association's *Schools with Sol*

Figure 5-2: Voltage Law and Pressure

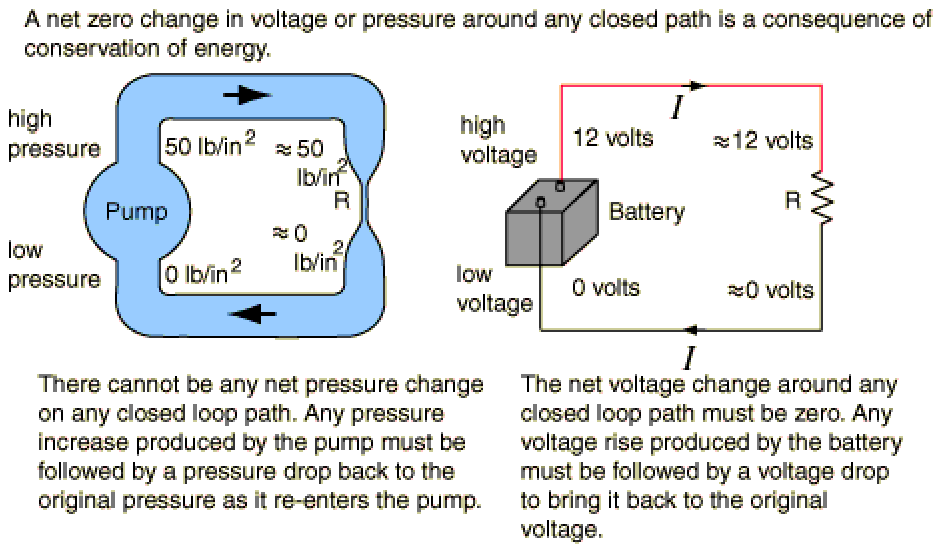
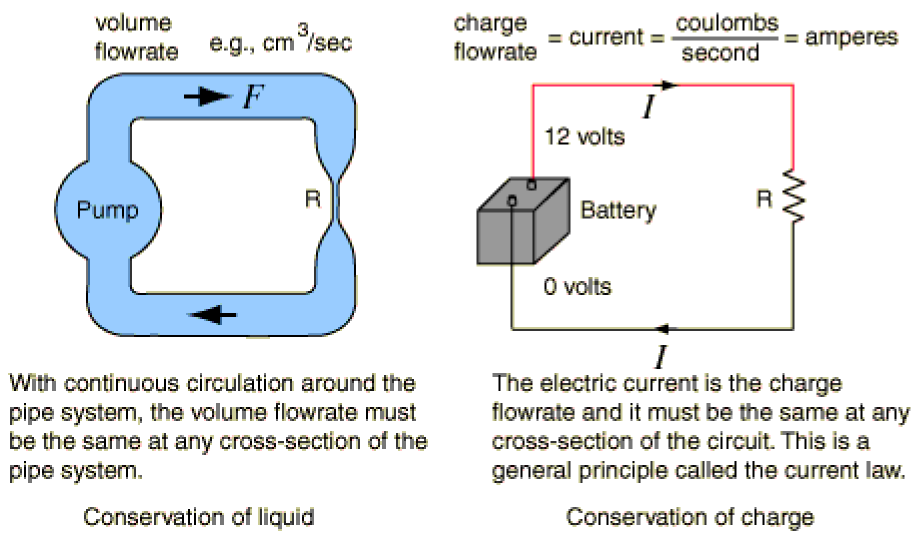


Figure 5-3: Current Law and Flow



These figures plus additional information on the “plumbing analogy” can be found at http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir2.html

Adapted from New Mexico Solar Energy Association's *Schools with Sol*

PHOTOVOLTAIC CELLS AND MODULES (Teacher's Guide)

Photovoltaic Facts

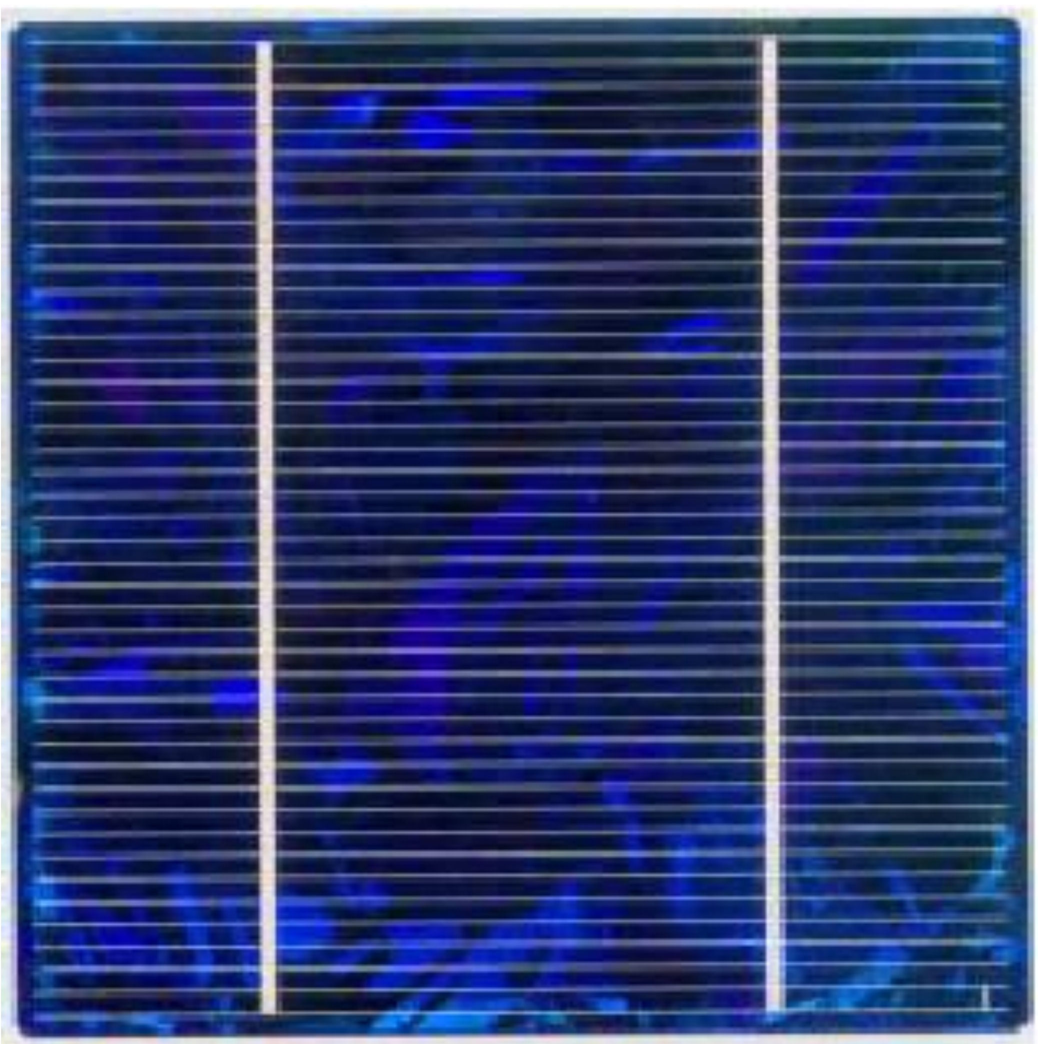
- Photovoltaic panels don't store energy like batteries.
- When photovoltaic panels are active (when they're exposed to sunlight) they "**transform"** or "**convert"** light energy into electrical energy.
- PV panels can be described as electrical generators or "batteries" that run on light.
- Since **electricity is essential for our modern lifestyle**, photovoltaic panels are extremely useful.
- The first practical PV cell was built by scientists at Bell Telephone Labs in 1954. It is now in a museum, and it still works just fine. Bell Labs called those first PV cells "Solar Batteries".
- The word "**photovoltaic**" was built from the Greek word "photo", meaning light, and the word "voltaic" which comes from Volt. A **Volt** is the unit of electrical pressure or electro-motive force.
- The **Volt** was named in honor of the Italian, **Alessandro Volta**, who built the first battery in 1798. That's why Volt is always capitalized.
- There are several different types of PV cells. Each type uses a different material to perform the light-to-electricity conversion. Some materials are better at this conversion than others.
- A **PV "cell**" is the most basic PV building block. The typical or "nominal" voltage of a PV cell doesn't depend on its size, but on what type of material is used to make the cell.
- The most common PV cells are made out of **silicon**, which is the main ingredient in ordinary beach sand ("Silicon" isn't the same thing as "Silicone"). Computer chips are also made out of silicon. A silicon PV cell has a nominal cell voltage of about ½ of a Volt.
- The two most critical things required to make a PV cell are **sand and brains** ! Why?
- The **area** of a PV cell determines how much **light energy** it can receive, and therefore how much **electrical energy** it can produce.
- PV cells can be connected together to form a **PV module** that has a higher nominal voltage and current rating (and therefore a higher power rating) than a single PV cell.
- PV cells and modules are "**polarized**", which means that they have a positive terminal and a negative terminal. When you use PV, you have to pay attention to which terminal is which !
- The **positive terminal** is usually marked with a plus sign (+) or a RED mark.
- The **negative terminal** is usually marked with a minus sign (-) or a BLACK mark.
- Since PV modules are polarized just like batteries, they can only be used in "direct current" or **DC circuits**.
- PV cells are rated by their **terminal voltage**, and by their **power output** in Watts.
- The nominal current generated by a PV cell is usually listed in **Amperes** (Amps or A), which tells you how much electrical current the cell can supply when it is exposed to light.
- If you multiply the nominal PV cell voltage by its rated current, you get its Watt rating. A **Watt** is a unit of **power** (that is, the amount of electrical energy generated per second).
- A PV panel rated at 100 Watts and exposed to full sunlight for one full hour, can generate 100 **Watt-hours** of electrical energy. At night, the PV panel won't generate any energy.
- The power rating of a PV cell will only be accurate if the cell is used EXACTLY the way that the cell manufacturer tested it (that is, with the same electrical load and the same amount of light).
- If less light falls on a PV cell than in the test case, the cell will generate about the same voltage, but less current, so it will generate less electric power. (W = V X A)
- PV cells don't "use up" the material that they are made of like batteries do. PV cells don't "wear out". Most PV modules are guaranteed to work for at least 25 years.
- PV cells don't need to be recharged the way some batteries do.
- Photovoltaic modules can be used to recharge lead-acid batteries. The electrical energy that the PV modules generate during the day can be stored in the batteries for use at night.

(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

Photovoltaic Cells

- Shown below is a "life-size" photo of the front of a single 5" X 5" **photovoltaic cell**.
- The dark (blue) material is specially processed silicon, made mainly from sand.
- The light colored lines are metal wires or "**conductors**" that are all tied together.
- The back of the cell is also lined with conductive metal, and the entire back is covered with a dark plastic coating.
- This PV cell is only 1/10 of an inch thick.
- When sunlight falls on the front of this PV cell, a voltage will be generated between the front conductors and the back conductors.
- If you attach a black (-) terminal to the metal on the front of the cell, and a red (+) terminal to the metal on the back of the cell, you'll have something that looks and acts just like a very flat battery (as long as the sun is shining).
- The test voltage of this PV cell is 0.481 V, and its test current is 4.8 Amps.

1) Multiply the cell's test voltage and current to get the cell's test power (wattage) rating.
   0.481 V x 4.8 Amps = 2.3 Watts
2) If this cell was reduced in size to 4" X 4", it would have about the same test voltage, but its test current would be only about 3.1 Amps. Does that make sense? Why? Yes, because the smaller cell would have less material or capacity to produce the current (Amps).



(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

Photovoltaic Modules

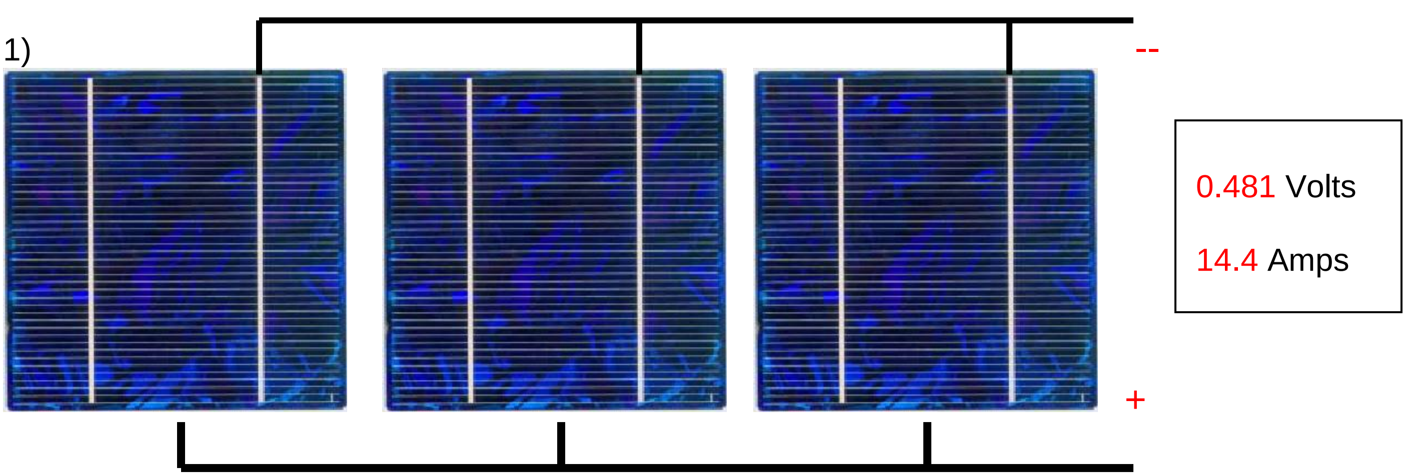
- PV **modules** are built by connecting two or more PV cells together.
- When two or more cells are **connected in series** (positive to negative), their voltages will add together, with each cell contributing its polarized voltage to the total.
- When two or more cells are **connected in parallel** (positive to positive, and negative to negative), their capacities will add together, with each cell adding its polarized current to the total.
- PV modules alone don't create a circuit, because there is no path for electrical current to flow from any cell's positive terminal to its negative terminal.

Building Simple PV Modules

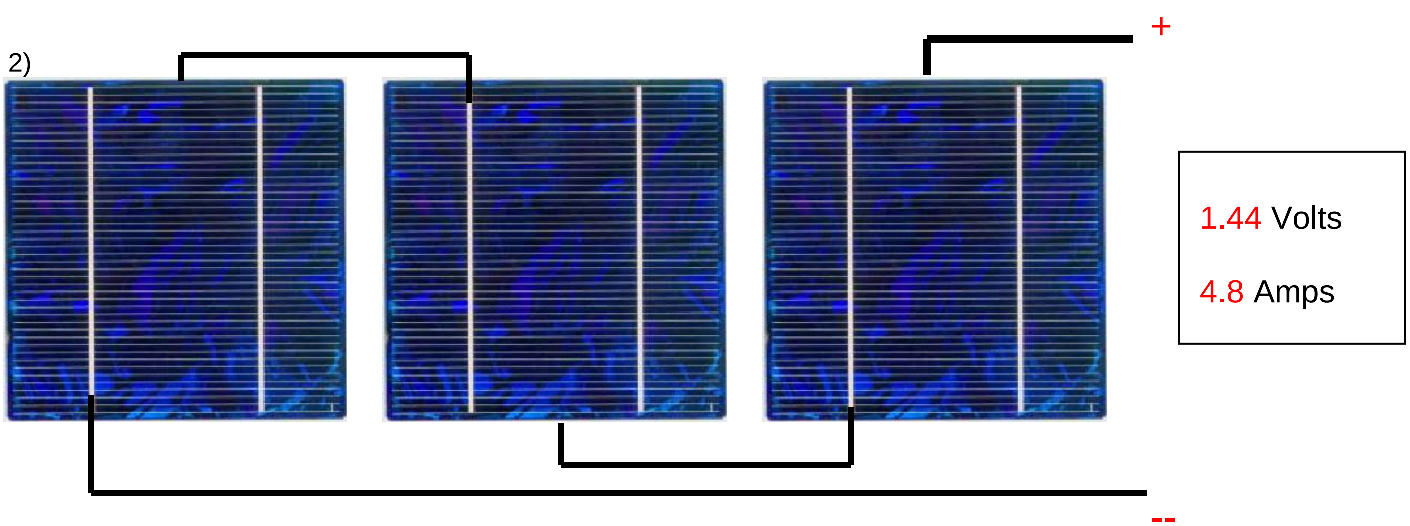
Two PV modules made from 5" cells connected in series or in parallel, are shown below.

1) Mark each cell's positive & negative wiring connections. (-- on front and + on back)
2) Mark the module's positive & negative output terminals. (See marks below.)
3) What will be the resulting module voltage and current rating for each one? (answers below)

1)



2)

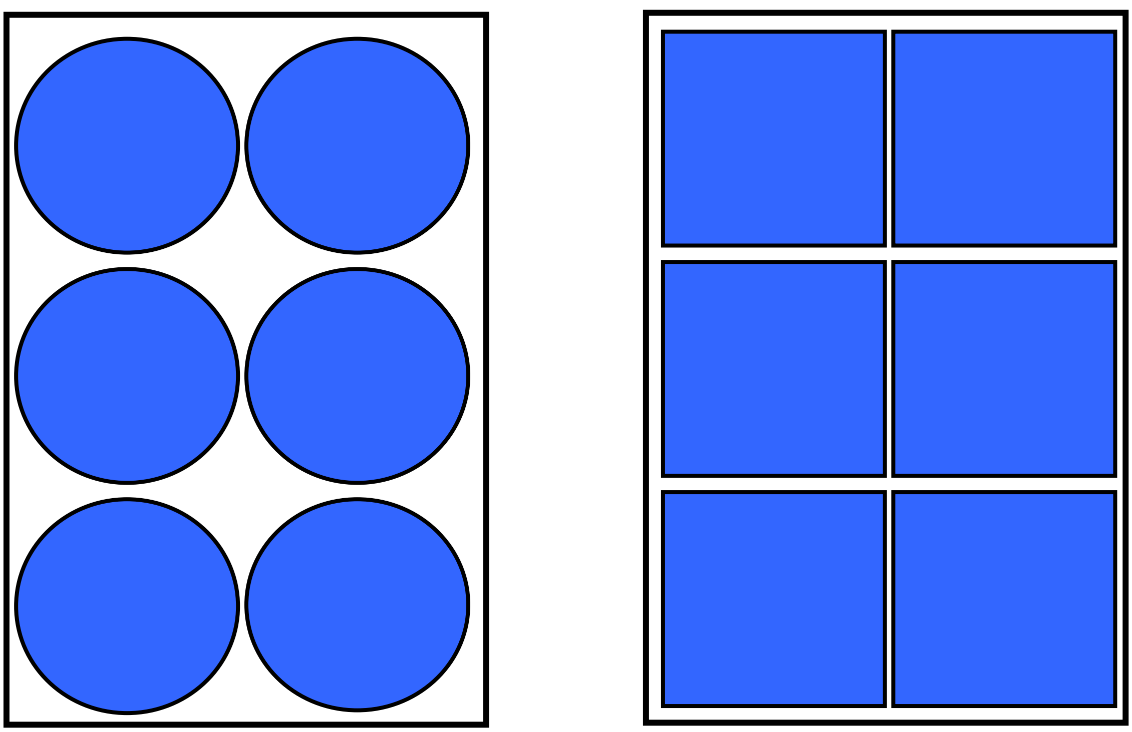


(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

Building Real Photovoltaic Modules

- There is more to building PV modules than just connecting multiple PV cells together.
- It's important to place the PV cells in a module as close to one another as possible. Why? You maximize the production for the given surface area.
- PV cells are manufactured by slicing thin sections off of a solid round tube (cylinder) of crystalline silicon, so the resulting slices will actually be round.
- Early PV modules were made by placing these round cells side by side.
- Now, almost all PV cells are re-shaped to be square, like the 5" X 5" cell we looked at.

1) How many PV cells are used in each of the PV modules below? 6 each
2) These two PV modules are packaged in the same sized frame. Which one will generate the most electrical power? Why? the one on the right because of more surface area
3) What is the maximum test voltage that these modules could have? How would their cells have to be connected in order to get that result? 6 x 0.481 V = 2.89 V in series
4) What is the minimum test voltage that these modules could have? How would their cells have to be connected in order to get that result? 1 x 0.481 V = 0.481 V in parallel



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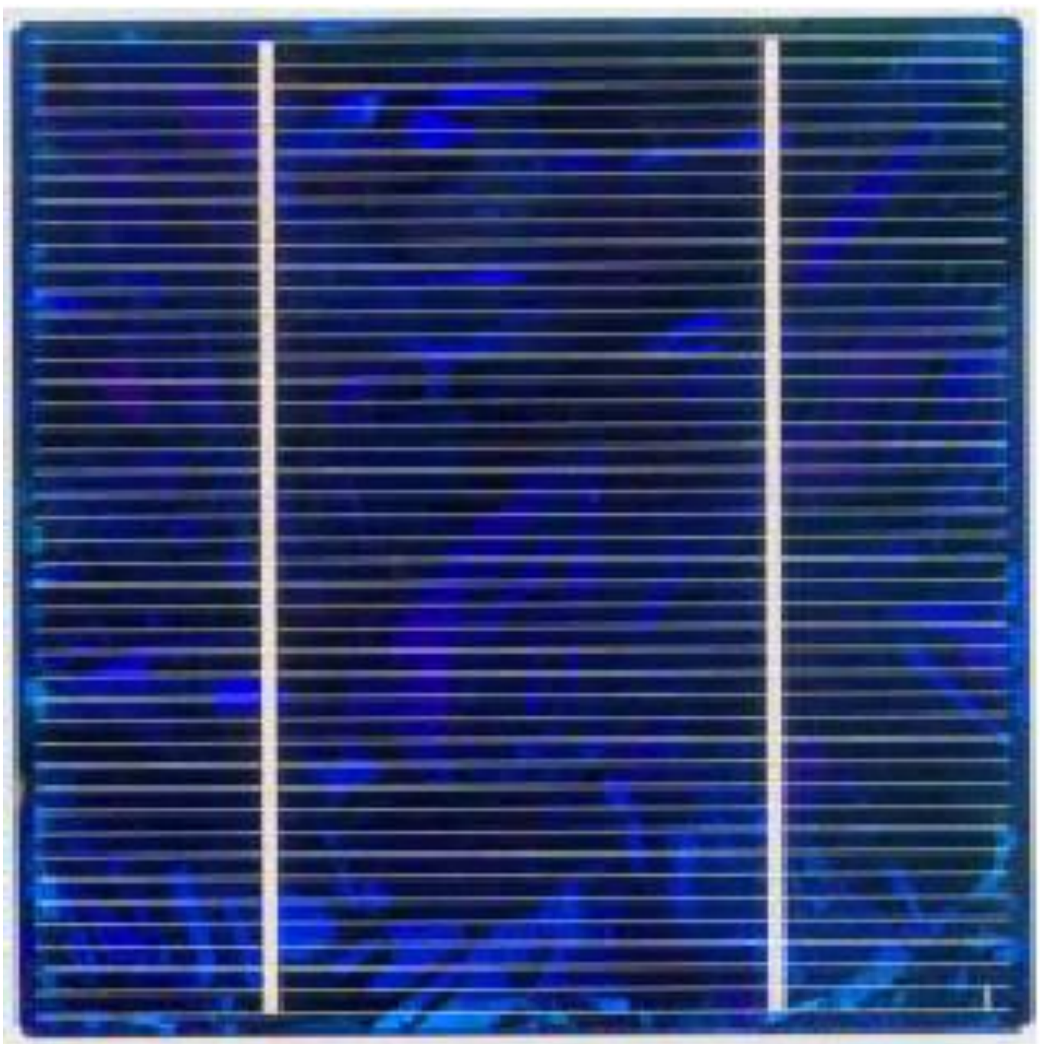
- The **negative terminal** is usually marked with a minus sign (-) or a BLACK mark.
- Since PV modules are polarized just like batteries, they can only be used in "direct current" or **DC circuits**.
- PV cells are rated by their **terminal voltage**, and by their **power output** in Watts.
- The nominal current generated by a PV cell is usually listed in **Amperes** (Amps or A), which tells you how much electrical current the cell can supply when it is exposed to light.
- If you multiply the nominal PV cell voltage by its rated current, you get its Watt rating. A **Watt** is a unit of **power** (that is, the amount of electrical energy generated per second).
- A PV panel rated at 100 Watts and exposed to full sunlight for one full hour, can generate 100 **Watt-hours** of electrical energy. At night, the PV panel won't generate any energy.
- The power rating of a PV cell will only be accurate if the cell is used EXACTLY the way that the cell manufacturer tested it (that is, with the same electrical load and the same amount of light).
- If less light falls on a PV cell than in the test case, the cell will generate about the same voltage, but less current, so it will generate less electric power. (W = V X A)
- PV cells don't "use up" the material that they are made of like batteries do. PV cells don't "wear out". Most PV modules are guaranteed to work for at least 25 years.
- PV cells don't need to be recharged the way some batteries do.
- Photovoltaic modules can be used to recharge lead-acid batteries. The electrical energy that the PV modules generate during the day can be stored in the batteries for use at night.

(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

Photovoltaic Cells

- Shown below is a “life-size” photo of the front of a single 5” X 5” **photovoltaic cell**.
- The dark (blue) material is specially processed silicon, made mainly from sand.
- The light colored lines are metal wires or “**conductors**” that are all tied together.
- The back of the cell is also lined with conductive metal, and the entire back is covered with a dark plastic coating.
- This PV cell is only 1/10 of an inch thick.
- When sunlight falls on the front of this PV cell, a voltage will be generated between the front conductors and the back conductors.
- If you attach a black (-) terminal to the metal on the front of the cell, and a red (+) terminal to the metal on the back of the cell, you’ll have something that looks and acts just like a very flat battery (as long as the sun is shining).
- The test voltage of this PV cell is 0.481 V, and its test current is 4.8 Amps.

1) Multiply the cell’s test voltage and current to get the cell’s test power (wattage) rating.
2) If this cell was reduced in size to 4” X 4”, it would have about the same test voltage, but its test current would be only about 3.1 Amps. Does that make sense? Why?



(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

Photovoltaic Modules

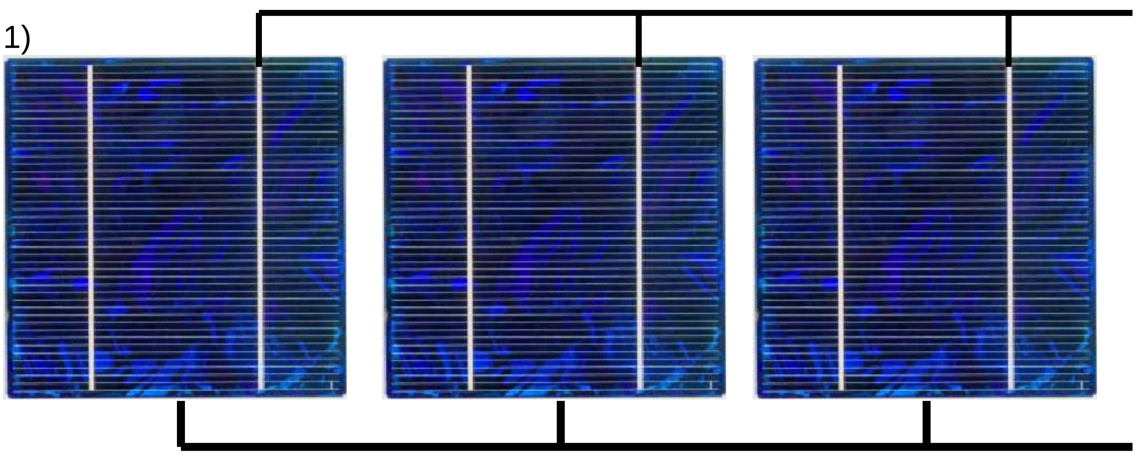
- PV **modules** are built by connecting two or more PV cells together.
- When two or more cells are **connected in series** (positive to negative), their voltages will add together, with each cell contributing its polarized voltage to the total.
- When two or more cells are **connected in parallel** (positive to positive, and negative to negative), their capacities will add together, with each cell adding its polarized current to the total.
- PV modules alone don't create a circuit, because there is no path for electrical current to flow from any cell's positive terminal to its negative terminal.

Building Simple PV Modules

Two PV modules made from 5" cells connected in series or in parallel, are shown below.

1) Mark each cell's positive & negative wiring connections.
2) Mark the module's positive & negative output terminals.
3) What will be the resulting module voltage and current rating for each one?

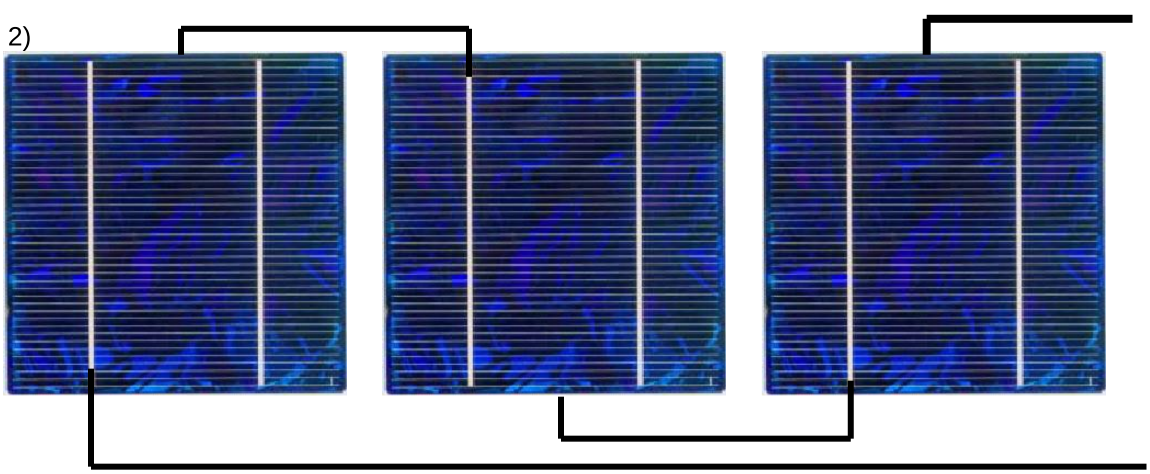
1)



_____Volts

_____Amps

2)



_____Volts

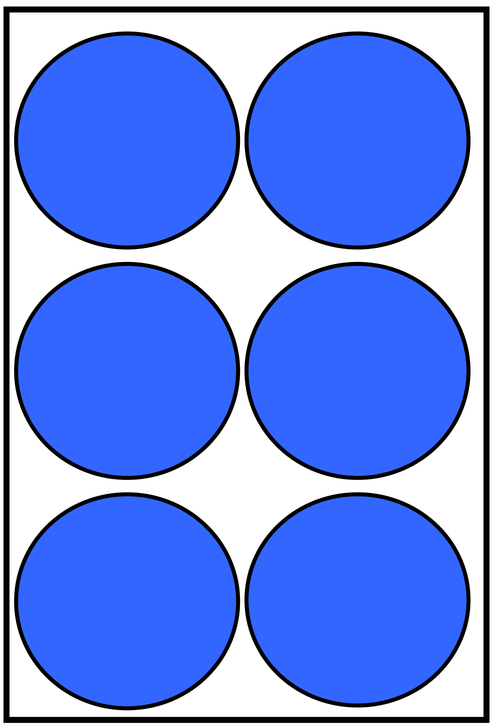
_____Amps

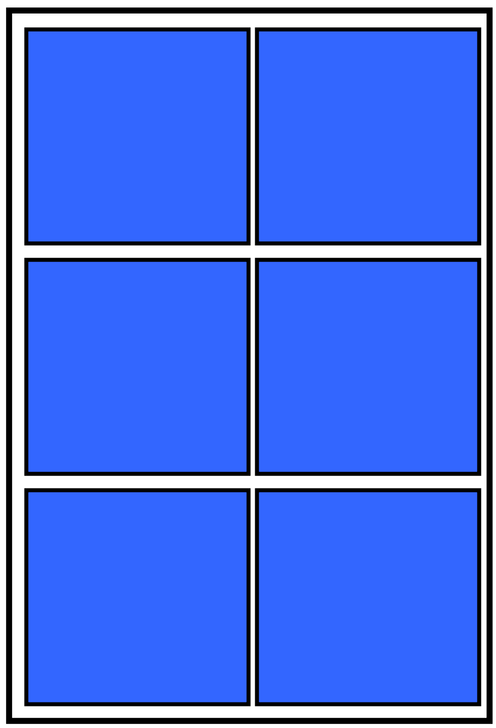
(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

Building Real Photovoltaic Modules

- There is more to building PV modules than just connecting multiple PV cells together.
- It's important to place the PV cells in a module as close to one another as possible. Why?
- PV cells are manufactured by slicing thin sections off of a solid round tube (cylinder) of crystalline silicon, so the resulting slices will actually be round.
- Early PV modules were made by placing these round cells side by side.
- Now, almost all PV cells are re-shaped to be square, like the 5" X 5" cell we looked at.

1) How many PV cells are used in each of the PV modules below?
2) These two PV modules are packaged in the same sized frame. Which one will generate the most electrical power? Why?
3) What is the maximum test voltage that these modules could have? How would their cells have to be connected in order to get that result?
4) What is the minimum test voltage that these modules could have? How would their cells have to be connected in order to get that result?





(Adapted from New Mexico Solar Energy Association's *Schools with Sol*)

BATTERY CELLS AND MODULES (Teacher's Guide)

Battery Facts

- Batteries **store energy** in a chemical form.
- When batteries are activated, they convert their chemical energy into electrical energy.
- Since **electricity is essential for our modern lifestyle**, batteries are extremely useful.
- The **first battery** was developed by Professor Alessandro Volta in Italy in 1798.
- The unit of electrical pressure or ***electro-motive force***, the **Volt**, was chosen to honor Professor Volta. The word Volt is always capitalized because it comes from his last name.
- There are many different types of batteries, and each type uses a different combination of chemicals to store energy.
- A **battery "cell"** is the simplest form of a battery. The typical or **"nominal" voltage** of a battery cell doesn't depend on its size, but on what chemicals are used to make the cell.
- The size of a battery cell determines how much chemical material it can hold, and therefore how much energy it can store. But the nominal voltage of a cell doesn't depend on its size.
- Common **battery cell types** and their typical cell voltage are:
  - Alkaline 1.5 V
  - Lead-Acid 2.0 V
  - Nickel Cadmium (NiCad) 1.2 V
  - Lithium Ion 3.0 V
- **Battery cells** can be connected together to form a **battery module** that has a higher voltage and a higher amount of stored energy than a single cell.
- Batteries are "**polarized**", which means that they have a positive terminal and a negative terminal. When you use a battery, you have to pay attention to which terminal is which !
- The **positive terminal** is usually marked with a plus sign (+) or a RED mark.
- The **negative terminal** is usually marked with a minus sign (-) or a BLACK mark.
- Since batteries are polarized, they can only be used in "direct current" or **DC circuits**.
- Batteries are rated by their **terminal voltage** and by their total "***capacity***" to store energy.
- The capacity of a battery is usually listed in **Amp-hours** (Ah) or in milli-Amp-hours (mAh), which tells you how much electrical current a new battery can supply for how long.
- If you multiply the nominal battery voltage by its rated capacity, you get the battery's nominal Watt-hour rating. A **Watt-hour** is a unit of electrical energy (1 Watt of power for one hour).
- The **capacity rating** of a battery will only be accurate if the battery is used EXACTLY the same way that the battery manufacturer tested it.
- If you use a battery in a circuit that needs a higher current flow (and therefore a higher power output) than in the test case, the battery's terminal voltage and capacity will be reduced.
- Some types of batteries are designed to be **recharged** many times. Other types of batteries are designed to be used only once.
- Alkaline batteries are not designed to be recharged.
- Lead-acid and NiCad batteries are designed to be recharged.
- Your family's car has a large 12 Volt **lead-acid battery** with a capacity of hundreds of Ah.
- Solar photo-voltaic systems use lead-acid batteries to store electrical energy for use at night.
- Lead-acid batteries are very heavy for their size. Why?
- The sulfuric acid used in lead-acid batteries can eat holes in your clothes and burn your skin.
- Lead is a metal, and it's very poisonous. Always recycle used lead-acid batteries.
- When a lead-acid battery is recharged, both hydrogen and oxygen gases are generated. What happens if an undiluted mixture of hydrogen and oxygen gas is exposed to a spark or a flame?

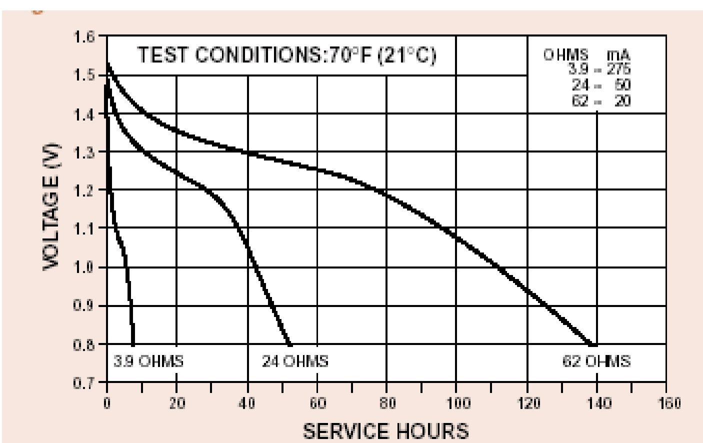
Common Batteries

Shown below are several "life-size" photos of **single cell alkaline batteries** that you've probably used. Notice that the **nominal voltage** of each cell is exactly the same, but the **capacity** of each cell is more or less proportional to how big each cell is.
Does that make sense? Why?

Have you used batteries like these in some of your own gizmos and gadgets? Yes
How many batteries of each size are used in each of your devices? Answers will vary.

Alkaline Size	Voltage (nominal)	Capacity mAh	Weight (grams)
AAA	1.5	1250	11.5
AA	1.5	2850	23
C	1.5	8350	66.2
D	1.5	20500	148

As an alkaline battery is used, the chemicals inside it will change, and the battery's terminal voltage and its capacity will be reduced. The graph below shows some typical performance data. As you can see, the longer an alkaline battery is used, the lower its voltage will be.
(Adapted from New Mexico Solar Energy Association's *Schools with Sol)*



Typical discharge profile of the DURACELL® alkaline MN 1500 ("AA" size) cell.

Reading the Graph:

If you install a new Duracell AA size alkaline battery in a circuit that draws 20 mA (milli-Amps), what will the battery terminal voltage be after 110 hours? 1 V

If you connect a 24 Ohm resistor across the terminals of a new Duracell AA size battery, how long will it take for the battery terminal voltage to reach 0.9 volts? 50 hrs

Do you think that an Energizer AA size battery will act about the same? Why? Yes--the AA capacity is the same.

Battery Modules

- Battery **modules** are built by connecting two or more battery cells together.
- When cells are **connected in series** (positive to negative), their voltages will add together, with each cell contributing its **polarized voltage** to the total.
- When cells are **connected in parallel** (positive to positive, and negative to negative), their **capacities** will add together, with each cell adding its **polarized capacity** to the total.
- Battery modules alone don't create a **circuit**, because there is no path for electrical current to flow from any cell's **positive terminal** to its **negative terminal**.
- If a **"short" circuit** (that is, a direct connection from Pos to Neg) is accidentally made when cells are connected, the cells will discharge very quickly and the battery module will fail.

Building Simple Battery Modules

Several battery modules made from cells connected in series or in parallel, are shown below.
1) Mark the positive and negative terminals of each module. (See marks below.)
2) Which modules have cells connected in series? In parallel? Series--1 & 2, Parallel--3
3) What will be the resulting voltage and capacity for each module? (See answers below.)

1) -- +

4.5_Volts

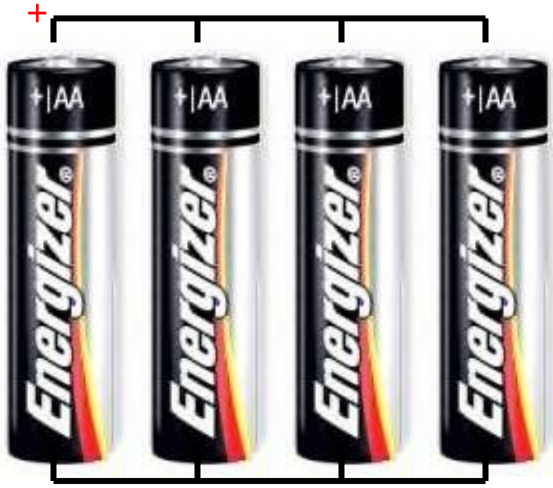
1,250 mAh

2) -- +

3.0 Volts

20,500 mAh

3) +



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1.5 Volts

11,400 mAh

Adapted from New Mexico Solar Energy Association's *Schools with Sol*

Building Complex Battery Modules

Several more complicated battery modules made from cells connected in series AND/OR in parallel are shown below.

1) Mark the positive and negative module terminals of each module. (See marks below.)

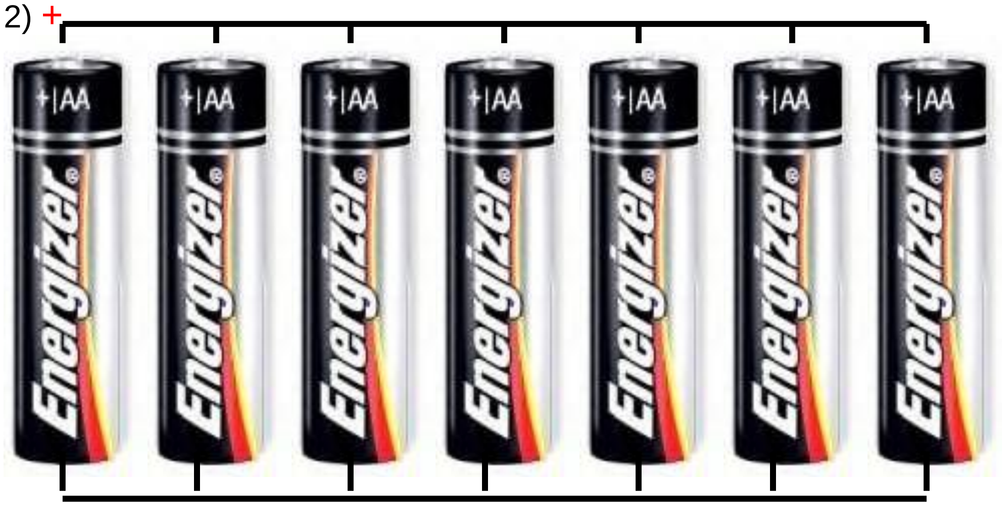
2) What will be the resulting module voltage and capacity for each one? (See answers below.)

1) --   +

4.5 Volts

2,500 mAh

2) +



--

1.5 Volts

19,950 mAh

One single cell alkaline battery would have the same voltage and slightly more capacity than this module. Which one? D cell at 1.5 V and 20,500 mAh

3)

+

--

6.0 Volts

2,500 mAh

Adapted from New Mexico Solar Energy Association's *Schools with Sol*

BATTERY CELLS AND MODULES (Student Guide)

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How many batteries of each size are used in each of your devices?

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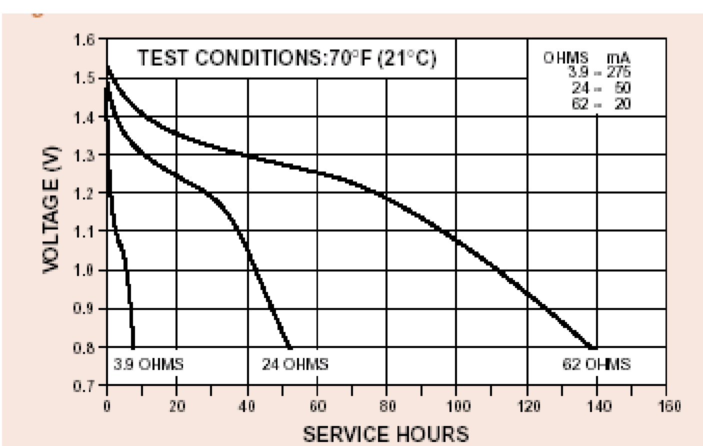
D	1.5	20500	148

As an alkaline battery is used, the chemicals inside it will change, and the battery’s terminal voltage and its capacity will be reduced. The graph below shows some typical performance data. As you can see, the longer an alkaline battery is used, the lower its voltage will be.
(Adapted from New Mexico Solar Energy Association's *Schools with Sol)*



Typical discharge profile of the DURACELL® alkaline MN 1500 (“AA” size) cell.

Reading the Graph:

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If you connect a 24 Ohm resistor across the terminals of a new Duracell AA size battery, how long will it take for the battery terminal voltage to reach 0.9 volts?

Do you think that an Energizer AA size battery will act about the same? Why?

Battery Modules

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- If a **"short" circuit** (that is, a direct connection from Pos to Neg) is accidentally made when cells are connected, the cells will discharge very quickly and the battery module will fail.

Building Simple Battery Modules

Several battery modules made from cells connected in series or in parallel, are shown below.
1) Mark the positive and negative terminals of each module.
2) Which modules have cells connected in series? In parallel?
3) What will be the resulting voltage and capacity for each module?

1)

_____Volts

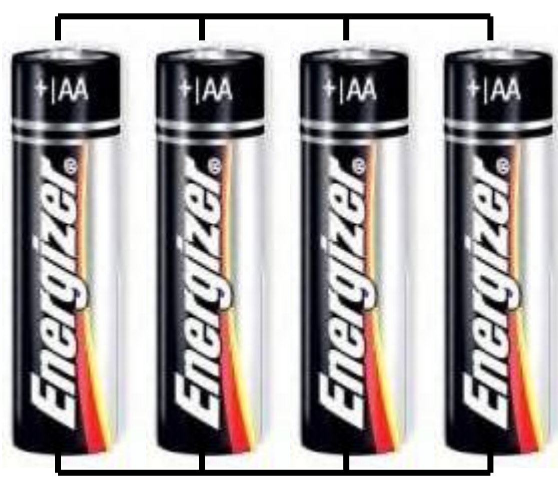
_____mAh

2)

_____Volts

_____mAh

3)



_____Volts

_____mAh

Adapted from New Mexico Solar Energy Association's *Schools with Sol*

Building Complex Battery Modules

Several more complicated battery modules made from cells connected in series AND/OR in parallel are shown below.

1) Mark the positive and negative module terminal of each module.

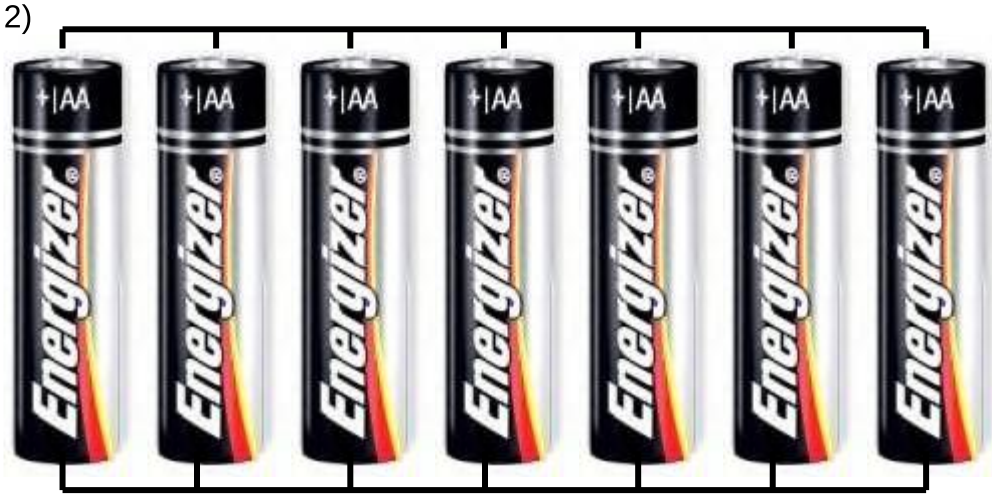
2) What will be the resulting module voltage and capacity for each one?

1)

_____Volts

_____mAh

2)



_____Volts

_____mAh

One single cell alkaline battery would have the same voltage and slightly more capacity than this module. Which one?

3)

_____Volts

_____mAh

Adapted from New Mexico Solar Energy Association's *Schools with Sol*

NMSEA SunChaser Photovoltaic Electricity
Discussion and Lab

Photovoltaic Energy: (diagram of solar cell, panel, and array, small solar panel and buzzer)

1. What is photovoltaic energy? electricity produced by solar electric panels

2. What devices have you seen operate with solar electric (photovoltaic) cells or panels? water fountain, toy race cars, electric butterfly etc. from SunChaser and solar battery charger, remote lighting and gate openers, etc.

3. What is electricity? energy from moving electrons in a circuit

4. How does a photovoltaic panel make electricity? Look at the diagram. What kind of energy makes the electrons flow in the circuit? Energy in the form of light or photons strike the solar cell and makes the electrons flow in the circuit. The cells are semiconductors.

5. Demonstration: Hook up the small solar panel to the buzzer (red to red and black to black). What happens to the sound of the buzzer as you move a piece of paper over the solar panel. It gets weaker as the paper covers more of the panel.

6. How are solar panels used to power a house? Look at diagrams of the grid-tied and stand-alone photovoltaic (PV) systems. The grid-tied house converts sunlight to DC electricity which is changed to AC electricity that household appliances use. Excess AC electricity is sent to the electric power grid for the neighbors to use. At night or on cloudy days, electricity supplied by the power company (usually made from coal or gas powered steam turbines) can be used.

The stand-alone system powers the house in the same way, except that it sends excess electricity to a battery bank for storage. This system uses stored PV electricity to operate the house at night or on cloudy days and may use a backup generator that runs on liquid or gas fuel for extra energy to charge the batteries if needed.

Electrical Energy: (diagrams showing comparisons between a water circuit and an electrical circuit--Figures 4-1, 4-2, and 5-1, a one gallon jug of water, an empty pan, two pieces of plastic tubing of two different diameters and about 5 ft long each)

1. Can you see or touch electricity? no, not the electricity itself

2. How did people know about electricity before scientists discovered electrons? lightning, static charge, magnetism

3. Can we imagine electricity by comparing it to something we can see and touch? yes, by using a water siphon

4. Demonstration: Start a siphon as shown in Figure 4-1. Compare the flow of water through the two different sizes of tubing by observing how far each one shoots water out when the ends are bent parallel to the pan that is catching the water. What is the difference in the distance that the water shoots out between the two sizes of tubing? The larger size shoots the water out farther than does the smaller one.

5. Raise the tubes up so that the ends are even with the jug. What happens to the water? Why? It stops flowing because of reduced pressure.

6. For the given pressure, which tube delivers the most power? Why? the larger one because of less resistance to flow

7. Can you write an equation for the relationship between the pressure and flow that explains why the water moves farther in the bigger tube and slows down when pressure is reduced by raising the tubes? Power = Pressure x Flow

8. What is power? the measurement of energy--the ability to do work

9. Look at the diagram of the siphon and equation. What would cause work (energy) to increase? either increasing the height of the container of water (pressure) or increasing the size of the tube (flow)

10. Look at the diagram of the electrical circuit? What would cause work (energy) to increase? either increasing the voltage of the battery or increasing the current through the circuit

11. Can you write an equation for the relationship between electrical force (electro-motive force) and the flow of electric charge (current) to produce the power to overcome the resistance of the wire plus the load (i.e. light bulb, door bell, etc.) in the circuit? Power (Watts) = electro-motive force (Voltage) x current (Amperage)

12. Look at the diagrams in Figure 5-1. What provides the pressure in the water circuit and what provides the electrical "pressure" or force in the electrical circuit? the pump and the battery.

Increasing or Decreasing Voltage in a Battery Circuit: (photo of a battery bank for a stand-alone PV system, battery module board, four AA 1.5-volt batteries, a multi-meter set at 20V DCV, diagrams of series and parallel connections)

1. Look at the diagram of the 1.5 V battery connections and then use the multi-meter set at 20 DCV to take the voltage measurement for one AA battery? 1.5 V

2. What is the voltage measurement for two AA batteries in series? 3 V
Three? 4.5 V Four? 6.0 V

3. Look at the diagrams of batteries wired in series and parallel. How can you increase the voltage of a battery module (bank) in an electrical circuit? by wiring the module in series

4. How can you increase the current of a battery bank without increasing voltage? you wire in parallel

5. What is the voltage measurement for the four AA batteries wired in parallel using the copper bus bar to make parallel connections? 1.5 V

6. Look at the diagram of the battery banks. Is the same amount of power obtained from both battery banks? yes, 24 V x 2 A = 48 W or 6 V x 8 A = 48 W

7. Where would you want to use parallel connections to wire a battery bank for low voltage and high current? in a stand-alone PV house system for safety

8. Look at the photo of the stand-alone PV system battery bank. Why are the wires connecting the batteries so big, like those used for car batteries? so that resistance from the wire is reduced allowing a larger current (flow of electric charge) for a smaller voltage (electro-motive force) to provide the needed power for the house

Wiring Solar Panels for Desired Voltage and Current: (photo of grid-tied PV system, three small solar panels, a multi-meter, diagrams of series and parallel connections, a data chart written on the board)

1. Connect the multi-meter set at 20V DCV to the wires from one of the solar panels (black to black and red to red). What is the measured voltage on one PV panel? about 4.5 V under room lighting

2. Connect two panels together in series by disconnecting the multi-meter red wire and connecting the first panel's red wire to the second panel's black wire. Measure the voltage as before. What is the measured voltage of two panels connected in series? about 8.3 V

3. Leaving the first two panels connected together, use the same procedure as in number 2 to connect the third panel in series. What is the measured voltage of the three panels connected in series? about 12.3V

4. What happens to voltage as you increase the number of panels wired in series in your solar array. it increases

5. Leaving all of the panels connected in series, set the multi-meter at 2 mA DCA. What is the measured mA of three panels in series. about 0.3 mA under room lighting

6. Disconnect the third panel and measure the mA. What is the measured mA of two panels in series. about 0.3mA How about one panel? 0.3mA

7. What happens to amperage as you connect more or less panels in series in a solar array. It stays about the same.

8. Leaving the multi-meter set at 2 mA, connect two panels in parallel (red to red and black to black). What is the measured mA of two panels in parallel ? 0.6 mA What is the measured mA of three panels in parallel? 0.9 mA

9. Set the multi-meter at 20V DCV. What is the voltage of three panels connected in parallel? 4.3V How about 2 panels in parallel? 4.2 V

10. What happens to amperage a you connect more panels in parallel? It increases.

11. What happens to voltage as you connect more or less panels in parallel? It stays about the same.

12. When would you want to increase voltage from your solar array while keeping amperage low? for a grid-tied solar array that requires a long distance wire run from the array to the load center at the house. You can use smaller wire for lower amperage. Copper wire is expensive! Also higher voltage from the array allows for more efficient conversion from DC to AC electricity in the inverter.

13. Example of possible results:

# of panels	Series V	Series mA	mWatts	Parallel V	Parallel mA	mWatts
1	4.5	0.3	1.4	4.5	0.3	1.4
2	8.3	0.3	2.5	4.2	0.6	2.5
3	12.3	0.3	3.7	4.3	0.9	3.9

14. As a PV designer and installer is it a good idea to understand the nature of electricity and how to wire electrical circuits in series and parallel? yes!

NMSEA SunChaser Photovoltaic Electricity
Discussion and Lab
Student Guide

Photovoltaic Energy: (diagram of solar cell, panel, and array, small solar panel and buzzer)

1. What is photovoltaic energy?

2. What devices have you seen operate with solar electric (photovoltaic) cells or panels?

3. What is electricity?

4. How does a photovoltaic panel make electricity? Look at the diagram. What kind of energy makes the electrons flow in the circuit? .

5. Demonstration: Hook up the small solar panel to the buzzer (red to red and black to black). What happens to the sound of the buzzer as you move a piece of paper over the solar panel. .

6. How are solar panels used to power a house? Look at diagrams of the grid-tied and stand-alone photovoltaic (PV) systems.

Electrical Energy: (diagrams showing comparisons between a water circuit and an electrical circuit--Figures 4-1, 4-2, and 5-1, a one gallon jug of water, an empty pan, two pieces of plastic tubing of two different diameters and about 5 ft long each)

1. Can you see or touch electricity?

2. How did people know about electricity before scientists discovered electrons?

3. Can we imagine electricity by comparing it to something we can see and touch?

4. Demonstration: Start a siphon as shown in Figure 4-1. Compare the flow of water through the two different sizes of tubing by observing how far each one shoots water out when the ends are bent parallel to the pan that is catching the water. What is the difference in the distance that the water shoots out between the two sizes of tubing?

5. Raise the tubes up so that the ends are even with the jug. What happens to the water? Why?

6. For the given pressure, which tube delivers the most power? Why?

7. Can you write an equation for the relationship between the pressure and flow that explains why the water moves farther in the bigger tube and slows down when pressure is reduced by raising the tubes?

8. What is power?

9. Look at the diagram of the siphon and equation. What would cause work (energy) to increase?

10. Look at the diagram of the electrical circuit? What would cause work (energy) to increase?

11. Can you write an equation for the relationship between electrical force (electro-motive force) and the flow of electric charge (current) to produce the power to overcome the resistance of the wire plus the load (i.e. light bulb, door bell, etc.) in the circuit?

12. Look at the diagrams in Figure 5-1. What provides the pressure in the water circuit and what provides the electrical "pressure" or force in the electrical circuit?

Increasing or Decreasing Voltage in a Battery Circuit: (photo of a battery bank for a stand-alone PV system, battery module board, four AA 1.5-volt batteries, a multi-meter set at 20V DCV, diagrams of series and parallel connections)

1. Look at the diagram of the 1.5 V battery connections and then use the multi-meter set at 20 DCV to take the voltage measurement for one AA battery?

2. What is the voltage measurement for two AA batteries in series?

Three?   Four?

3. Look at the diagrams of batteries wired in series and parallel. How can you increase the voltage of a battery module (bank) in an electrical circuit?

4. How can you increase the current of a battery bank without increasing voltage?

5. What is the voltage measurement for the four AA batteries wired in parallel using the copper bus bar to make parallel connections?

6. Look at the diagram of the battery banks. Is the same amount of power obtained from both battery banks?

7. Where would you want to use parallel connections to wire a battery bank for low voltage and high current?

8. Look at the photo of the stand-alone PV system battery bank. Why are the wires connecting the batteries so big, like those used for car batteries?

Wiring Solar Panels for Desired Voltage and Current: (photo of grid-tied PV system, three small solar panels, a multi-meter, diagrams of series and parallel connections, a data chart written on the board)

1. Connect the multi-meter set at 20V DCV to the wires from one of the solar panels (black to black and red to red). What is the measured voltage on one PV panel?

2. Connect two panels together in series by disconnecting the multi-meter red wire and connecting the first panel's red wire to the second panel's black wire. Measure the voltage as before. What is the measured voltage of two panels connected in series?

3. Leaving the first two panels connected together, use the same procedure as in number 2 to connect the third panel in series. What is the measured voltage of the three panels connected in series?

4. What happens to voltage as you increase the number of panels wired in series in your solar array.

5. Leaving all of the panels connected in series, set the multi-meter at 2 mA DCA. What is the measured mA of three panels in series.

6. Disconnect the third panel and measure the mA. What is the measured mA of two panels in series. How about one panel?

7. What happens to amperage as you connect more or less panels in series in a solar array.

8. Leaving the multi-meter set at 2 mA, connect two panels in parallel (red to red and black to black). What is the measured mA of two panels in parallel ? What is the measured mA of three panels in parallel?

9. Set the multi-meter at 20V DCV. What is the voltage of three panels connected in parallel? How about 2 panels in parallel?

10. What happens to amperage a you connect more panels in parallel?

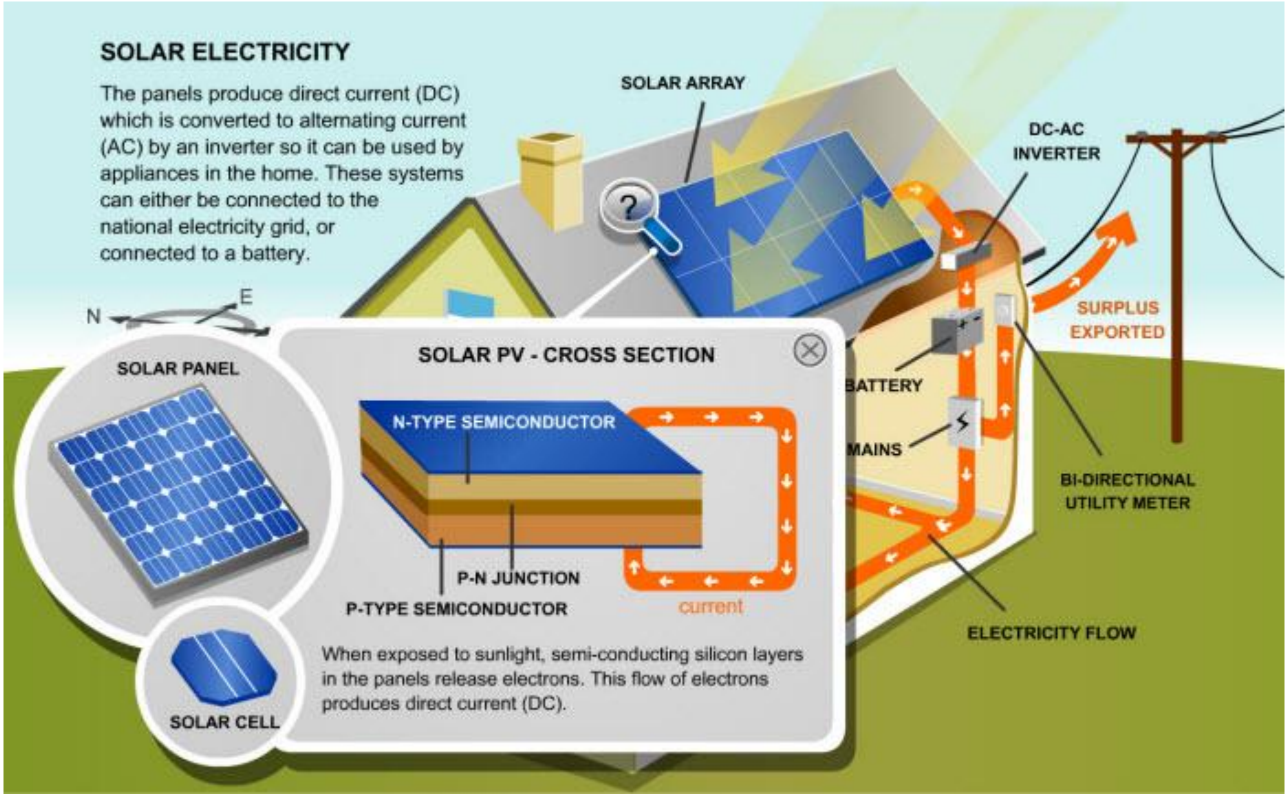
11. What happens to voltage as you connect more or less panels in parallel?

12. When would you want to increase voltage from your solar array while keeping amperage low?

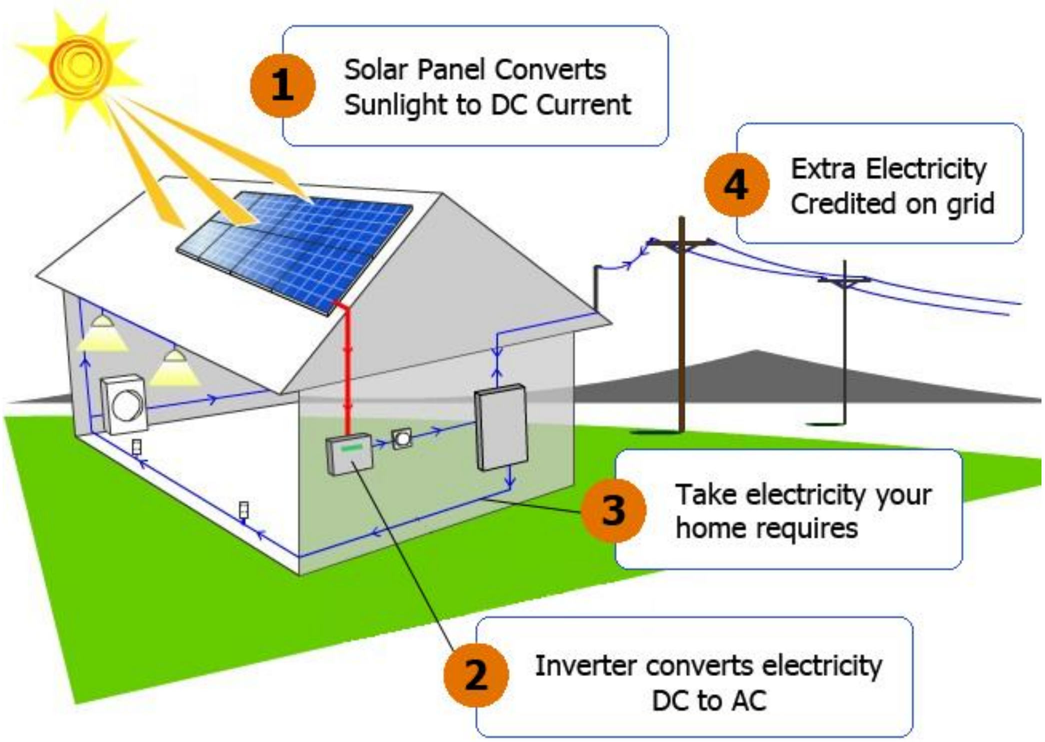
13. Example of possible results:

# of panels	Series V	Series mA	mWatts	Parallel V	Parallel mA	mWatts
1						
2						
3						

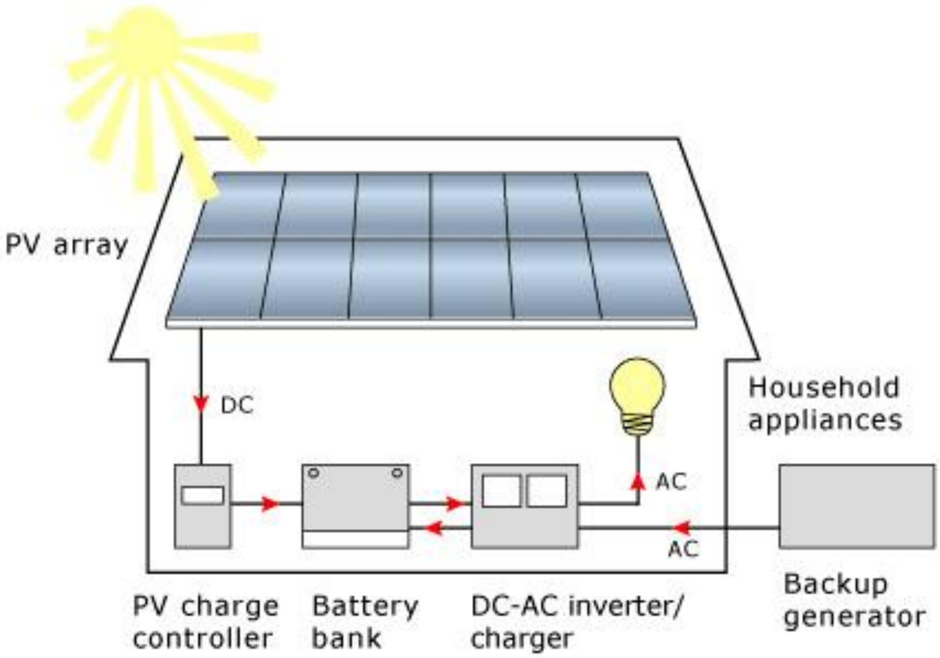
14. As a PV designer and installer is it a good idea to understand the nature of electricity and how to wire electrical circuits in series and parallel?



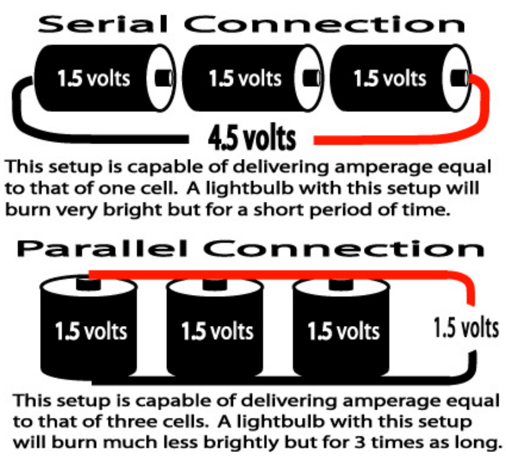
PHOTOVOLTAIC ENERGY

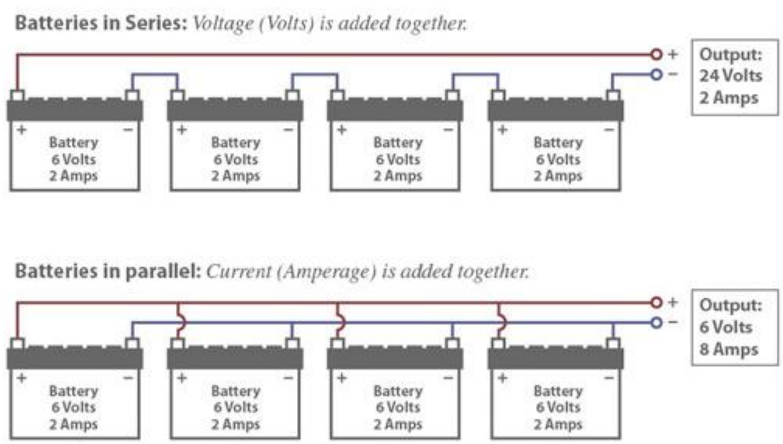


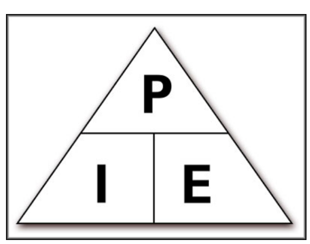
GRID-TIED PHOTOVOLATAIC SYSTEM



STAND-ALONE PHOTOVOLTAIC SYSTEM







POWER (Watts) = CURRENT INTENSITY (Amps) X ELECTROMOTIVE FORCE (Volts)

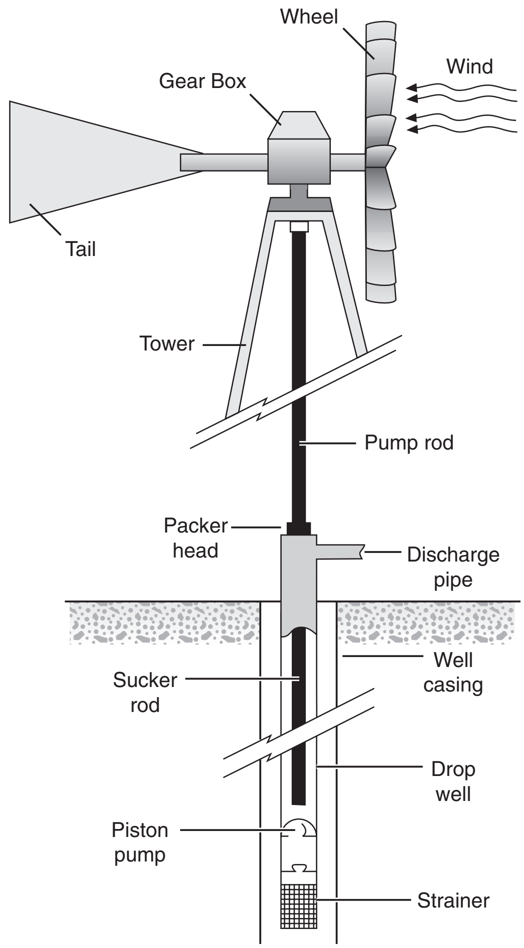
Wind Power Basics

RENEWABLE ENERGY
THE INFINITE POWER
OF TEXAS

SECO FACT SHEET **NO. 13**

HIGHLIGHTS

- **Wind power is one of the oldest renewable technologies**
- **As wind speed doubles, power generation capability increases eightfold**
- **Higher is better: hilltops and tall towers lead to greater energy production**
- **Unlike fossil fuels, wind power cannot be depleted and produces no pollution**



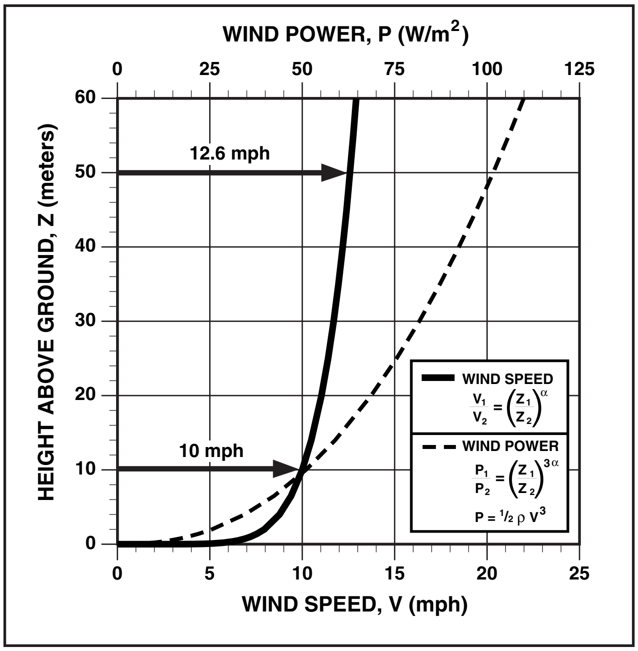
Mechanical pump windmill
These simple wind-driven machines, which utilize a long sucker rod to pump underground water to the surface, were a critical tool in settling the West.

SUMMARY

Humans have been harnessing the wind ever since farmers in ancient Persia figured out how to use wind power to pump water. Wind power turns the kinetic energy of the wind into mechanical or electrical power than can be used for a variety of tasks. Whether the task is creating electricity or pumping water, the wind offers an inexpensive, clean and reliable form of power. Wind farms are now part of the Texas landscape with 187 megawatts (MW) installed from 1995-2000. An additional 500 MW are in development for 2001.

WIND ON THE WATER

Whether powering sailboats across the surface of the water or pumping water from one location to another, the wind is a good source of power. Wind provided early explorers with the engine they needed to cross oceans and discover new lands. On land, the oldest and most widespread use of wind power is for pumping water. In virtually every country on earth, humans are using wind power to either pump water from the ground or move it from one location to another. Here in



Typical wind shear profile *Speed and power available in the wind increases with increasing elevation. The relationship is commonly referred to as the one seventh power law (a=1/7)*

Texas, where more than 80,000 windmills are in use, rural residents have long relied on windmills to provide water for livestock and human use.

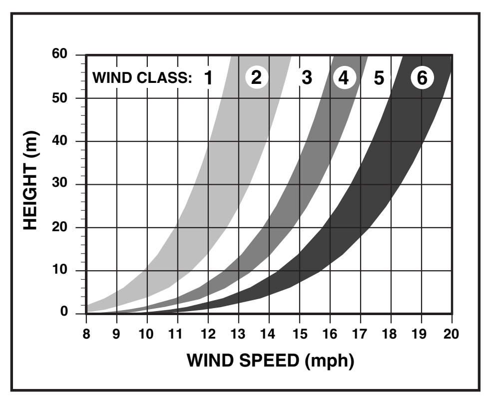
THE HOWS AND WHYS OF WIND POWER

Wind is moving air. The engine that drives this movement is the sun. A good illustration is the sea breeze that blows along the Texas Gulf coast. As the coastal land soaks up sunshine, the air above it heats up and rises. Air over the cooler ocean water then rushes inland. The result is a very dependable wind source suitable for making anything from electricity to windsurfing.

Although modern wind turbines can produce some electricity in light winds, the stronger the breeze the better. Why? The power available in the wind is proportional to the cube of its speed. That means that if the wind speed doubles, say from 10 to 20 miles per hour, the power available to a wind generator increases by a factor of eight, for instance from 1,000 Watts to 8,000 Watts.

One easy way to access higher wind speeds is simply to go up. Winds high above the ground are stronger than winds near the ground. On average a five-fold increase in elevation, say raising the height of the wind machine from 10 feet to 50 feet, will result in twice as much available wind power. That's why wind turbines are perched on tall towers and are often located on mountains or hilltops.

Given the need for strong winds, finding the best sites for commercial wind farms is critical. The location of power plants fueled by wind must be near existing power lines and in the windiest sites available. To compete head-to-head with fossil fuel generating technologies, wind turbines are best located in areas where wind speeds are 16-20 mph at 50 m height. Wind farms are located in the most windy areas and close to utility power lines. In Texas, the best



Wind power depends on elevation and wind speed *Wind Class is a relative scale used to characterize wind potential of any location. Wind Class of 3 and above are generally regarded as being suitable for commercial wind farm development.*

locales are found in West Texas and the Texas Panhandle.

Air temperature is also an important factor in wind power generation. Cold air is more dense than hot air. Thus, wind turbines are able to generate about 5% more power at any given wind speed in the winter than they are during the hot days of summer.

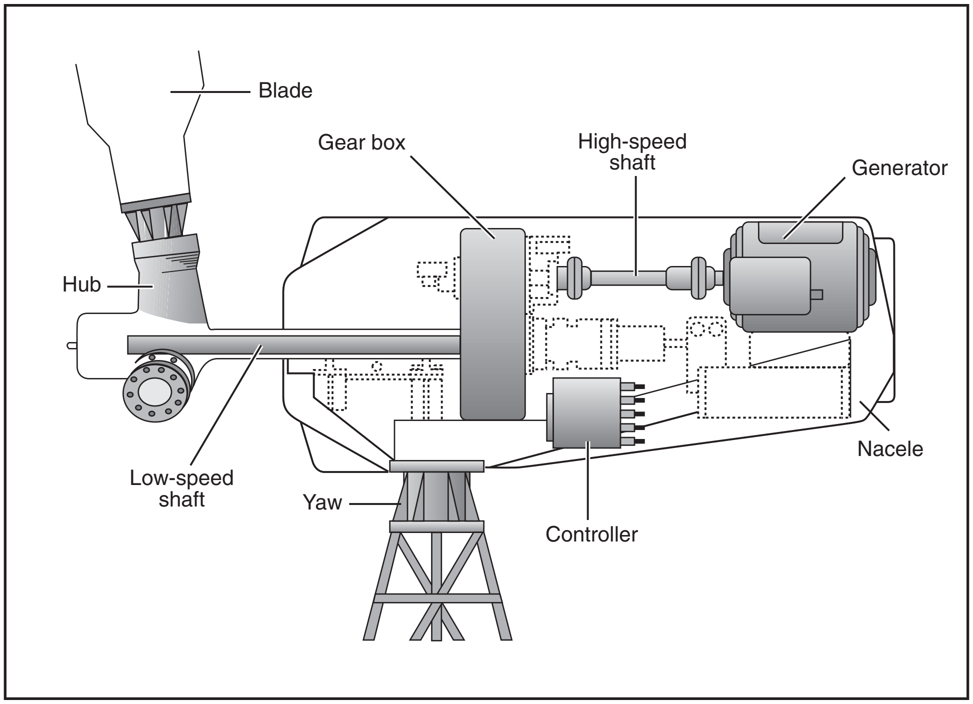
MAKING WATTS FROM WIND

The blades on a wind turbine are similar to the propeller blades on an airplane. The rotor blades generate lift from the passing wind, causing them to rotate the hub of the turbine. The rotating action of the hub then turns a generator, which creates electricity. A gearbox is generally necessary to optimize the power output from the machine. That power is then either fed into the electric grid or stored in batteries for use on-site.

While wind speed is important, so is the size of the rotor. On a turbine, the power available to the blades is proportional to the square of the diameter of the rotor. In other words, simply by making the turbine blades twice as long and beefing up the generator, you increase the power producing capability of the turbine by a factor of four.

Modern wind turbines come in two varieties: horizontal axis and vertical axis. Horizontal axis turbines have blades that spin on an axis that is parallel to the ground. These systems often look like the propeller on an airplane. Vertical axis systems have blades that spin on a vertical axis giving them an appearance somewhat like giant egg beaters.

Although large utilities are getting the most attention for their move into wind power, rural residents in all 50 states and dozens of foreign countries have quietly been installing small-scale wind generation systems. These systems can be obtained for as little as $1,000 and are perfect compliments to photovoltaic systems. Several vendors sell ready-made towers and turbines that are easily installed.



Electricity generating wind turbine *The major components of this device are the blades, shaft, gearbox and generator. On large machines, additional controllers and drive motors ensure that the machine is positioned for optimal capture of the wind.*

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RESOURCES

FREE TEXAS RENEWABLE ENERGY INFORMATION

For more information on how you can put Texas' abundant renewable energy resources to use in your home or business, visit our website at **www.InifinitePower.org** or call us at 1-800-531-5441 ext 31796. Ask about our free lesson plans and videos available to teachers and home schoolers.

ON THE WORLD WIDE WEB:

Frequently asked questions/technical advice at **American Wind Energy Association**
www.awea.org/faq/index.html

Lots of information, wind energy and wind turbines: **Danish Wind Turbine Manufacturers Association**
www.windenergy.dk

For home owner size wind turbines
homepower.com/download2.htm#Wind

BOOKS:

Wind Energy and Wind Turbines. Vaughn Nelson, AEI, Revised September 2000. (Available from the Alternative Energy Institute)

Introduction to Wind Energy. Vaughn Nelson, Earl Gilmore and Kenneth Starcher, AEI Report 94-2. (Available from the Alternative Energy Institute)

Wind Characteristics, An Analysis for the Generation of Wind Power. Janardan Rohatgi and Vaughn Nelson, 1994. (Available from the Alternative Energy Institute)

Wind Energy Basics, A Guide to Small and Micro Wind Systems.
Paul Gipe, Chelsea Green Publishing, 1999.

ORGANIZATIONS

Alternative Energy Institute
Box 60215, WTAMU
Canyon, TX 79016
(806) 651 2295
www.wtamu.edu/research/aei or
www.windenergy.org

American Wind Energy Association
122 C Street, N.W.
Washington, D.C. 20001
(202) 383-2505
www.awea.org

CADDET
Center for Renewable Energy
1617 Cole Blvd
Golden, CO 80401-3393
(303) 275-4373
www.caddet-re.org

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 275-3000
www.nrel.gov

Texas Solar Energy Society
P. O. Box 1447
Austin, TX 78767-1447
(512) 326-3391
e-mail: info@txses.org
www.txses.org

Texas Renewable Energy Industries Association
P. O. Box 16469
Austin, TX 78761
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www.treia.org

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RENEWABLE ENERGY
THE INFINITE POWER
OF TEXAS

Testing a Windmill Generator & Wind Power Basics

Target Grade Levels
Ninth - Twelfth

Time
Two 1-hour periods

Materials
- small electric fan or hair dryer
- small DC toy motor
- cork (at least 2 cm in diameter)
- DC voltmeter
- stiff ruler
- 50 cm of thin electrical wire with alligator clips
- rubber band
- scotch tape
- paper clips
- wire cutters
- scissors
- piece of cardboard
- goggles

Knowledge and Skills (TEKS)
- Science:
  - Describe energy systems, observe change and consistency, and make inferences and predictions;
  - Analyze effects and record data of heating and cooling; and
  - Explain different types of climate and the factors that influence climate regions.
- Math:
  - Show relationships using tables; and
  - Construct graphic organizers.
- Language Arts:
  - Gather credible information; and
  - Develop drafts, revise, edit.

Overview
Students will learn the best locations in Texas for utilizing wind power. Students will construct and test a windmill to observe how design and position affect the electrical energy produced. Appreciation for the benefits of renewable energy sources is a focus.

Background Information
Wind power is one of the oldest renewable technologies. Wind is caused when warm air rises, and cooler air rushes in to fill the space. The turbines change this wind energy into mechanical power. Turbines require a minimum wind speed of about 15 miles per hour to generate electricity economically. As wind speed doubles, power generation capability increases eightfold, and the higher the turbines are placed, for example, on a tall hill or tower, the greater energy production. Unlike fossil fuels, wind power cannot be depleted and produces little pollution.

Suggested Reading
- *Wind Energy and Wind Turbines*. Vaughn Nelson, AEI, Revised September 2000. (Available from the Alternative Energy Institute)
- *Introduction to Wind Energy*. Vaughn Nelson, Earl Gilmore and Kenneth Starcher, AEI Report 94-2. (Available from the Alternative Energy Institute)
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- *Wind Energy Basics, A Guide to Small and Micro Wind Systems*. Paul Gipe, Chelsea Green Publishing, 1999.

Procedure

1) Vocabulary
   a) ammeters
   b) convection
   c) current
   d) direct current (DC)
   e) electrical power
   f) electricity
   g) fossil fuel
   h) gearbox
   i) kinetic energy
   j) mechanical power
   k) renewable energy
   l) turbines
   m) variable
   n) voltage
   o) voltmeter

2) Activities
   a) The teacher should read the student activity first. This activity presumes that students can connect a small direct current (DC) motor and voltmeter (an electrical connector clamp can be used). Emphasize to the class safety precautions when taking current and voltage readings using volt- and ammeters. Use either meter leads that have alligator clips on the ends, or attach insulated alligator clips to the wire ends that come into contact with the meter leads. Students should never touch any bare or exposed metal in a circuit that is generating electricity (i.e. meter leads, bare wire, etc.). Students should read W*ind Power Basics*, before reviewing the activity. Safety instructions should be reviewed. Voltmeter readings should be taken safely. For example, attach insulated alligator clips on the ends of the wire to safely clip on to the voltmeter leads. Discuss safety procedures for using the fan.
   b) Basic concepts of electricity, such as current flow, operation of a magnetic coil motor and generation of electricity can be discussed. Discuss the diagram of the major components for generating electricity in the W*ind Power Basics* handout. Students can draw a concept map for the wind turbine and the functions of its parts.
   c) Students should outline the instructions, before class, using very few words to summarize. Before performing the experiment, students should plan some of the variations they will change in the design. Extra cardboard will be needed for altering blade sizes. Discuss the advantages of using a renewable energy source, rather than fossil fuels. Point out (from the W*ind Power Basics* handout) the results of doubling wind speed (which increases power output eight times) and where to locate wind turbines. Using the Internet for more information, students can research wind turbines as to what they are, where they are found, what uses they have, when they are most effective, and how they work.
   d) Once the instructions to the initial lab exercise have been completed, experimenting with the variables provides students with opportunities to enhance their understanding. Variables can include changing length and width of blades, using different weights of cardboard for the blades, changing wind velocity, and using different angles for the blades. Students should record their variables and results in a data chart they create

during the activity. As students change blade length, width, weight or angle, they should predict whether the amount of voltage will increase or decrease.

e) Students can share and compare the variables they used and the effects on electricity generation. Research on historical uses of wind power will enrich their understanding. How wind develops from sunshine is a major concept. Students can keep track of wind speed in your area for two weeks and consider if wind power would be beneficial as an investment there.

f) Constructing the Windmill Generator (wear goggles)

   i) Use the rubber band to attach the small electric motor to the flat end of the ruler with the motor shaft extending towards the edge of the ruler.

   ii) If the motor doesn't already have wires attached, cut the piece of wire into two pieces and add these two wires to each of the motor's outlets.

   iii) Follow your teacher's safety instructions and attach the two wires to a DC voltmeter using the alligator clips.

   iv) Take four paper clips and straighten out the lower part of each clip. Clip off enough of this straight part, so that only one centimeter (cm) sticks out.

   v) Cut out four pieces of cardboard two cm by 25 cm. Tape these four blades onto the central part of each paper clip.

   vi) Using the one cm part of the paper clip that sticks out, insert the blades into the sides of the cork, .5 cm from the small end of the cork. Be sure to space the blades equally around the circumference of the small end of the cork.

   vii) Place the large cork end, which is furthest away from the wind blades, into the motor shaft. Make sure the shaft goes into the exact center of the cork.

g) Performing the Experiment (wear goggles)

   i) Rotate the blade in the cork so that it is at a 45^{o} angle to the flat plane of the edge of the ruler. Place the windmill 30 cm away from the fan or hair dryer (your distance may vary depending on the strength of the wind source). Turn on the fan or hair dryer. Measure the voltage produced. Try rotating the blades of the windmill to see which angle produces the greatest voltage.

   ii) Design your own set of wind blades, discussing with your lab partner(s) which size and shape, and what number of blades, will work best. Attach these new blades to the motor and try adjusting them at various angles to produce the greatest voltage. Place the windmill at the same distance from the wind source. Measure the voltage again. Place all of your measurements in a data chart.

   iii) Determine the most efficient blade size and shape (sketch and record the dimensions). Next explore how wind velocity affects the amount of electricity produced by changing the fan speeds. (Be sure to keep the windmill at the same distance each time.) Record your measurements in a data chart. Discuss with your teacher other variables you might use.

3) Review
   Discuss results.

4) Evaluation
   a) Short Answer Questions
      i) What changes to a windmill can improve its efficiency?
      ii) Draw a map of Texas and shade in the areas where wind power is best generated.
      iii) Cite three reasons for using wind power, now and in the future.
   b) Answers for Short Answer Questions
      i) Improving efficiency can be accomplished by changing length and/or width of the blades, changing the angle of the blades, altering blade weight and also insuring that the windmill is positioned on an optimum site where the wind is quite constant.
      ii) Students can practice drawing a map of Texas from memory, which also aids their ability to locate major Texas cities. The areas in the Panhandle and West Texas as well as part of the coast should be shaded. Students can describe the kinds of environments they have shaded by doing some research, using a variety of sources.
      iii) Wind power is renewable, cost effective to use, will reduce our consumption of imported energy, does not pollute the environment and can be delivered through the existing power grid.
   c) Multiple Choice Questions
      i) As an engineer working with renewable energies you would:
         (1) place wind farms in valleys and low lying areas
         (2) place wind farms where weather fronts are calm
         (3) place wind farms on elevated sites
         (4) build wind farms everywhere
      ii) Wind power turns the kinetic energy of wind into:
         (1) direct heat
         (2) solar energy
         (3) hydroelectric power
         (4) both mechanical and electrical power
      iii) Wind power:
         (1) is one of the oldest renewable technologies
         (2) was used by early sailors
         (3) is used to pump water
         (4) all answers a, b, & c

iv) Wind:
(1) is moving air
(2) is created by the sun’s energy
(3) has power proportional to the cube of its speed
(4) all answers a, b, and c

v) You will likely most often see wind turbines:
(1) on rivers
(2) on hilltops
(3) on lakes
(4) in cities

vi) Learning about renewable energy sources:
(1) is necessary for the future
(2) will help future decision making
(3) shows you other ways to create electricity
(4) all answers a, b, and c

vii) Wind energy is:
(1) an important energy source
(2) kinetic energy
(3) movement of energy from the air
(4) all answers a, b, and c

viii) Some of the devices used in wind power are:
(1) turbines
(2) sails
(3) windmills
(4) all answers a, b, and c

ix) Wind is:
(1) caused by convection
(2) a determiner of weather
(3) a form of fossil energy
(4) a and b

x) Hot air:
    (1) is heavier than cold air
    (2) rises
    (3) sinks
    (4) a and c

d) Answers to Multiple Choice Questions
    i) Question #1, 3
    ii) Question #2, 4
    iii) Question #3, 4
    iv) Question #4, 4
    v) Question #5, 2
    vi) Question #6, 4
    vii) Question #7, 4
    viii) Question #8, 4
    ix) Question #9, 4
    x) Question #10, 2

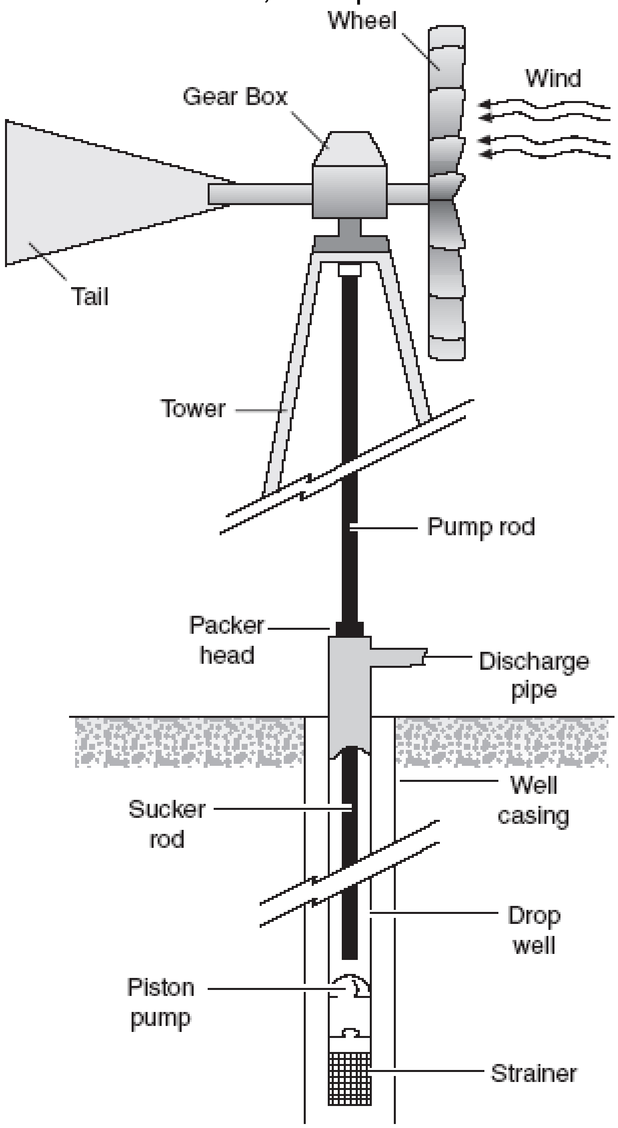
5) Extension
    a) Have a representative of the local electric utility discuss their wind energy program.
    b) Have a representative of a windmill manufacturer visit to discuss construction and use of windmills nationwide.
    c) Have students research the drawbacks (bird kill, noise, etc.) of wind power and write a comprehensive paper citing pros and cons.

Adapted from: “Researching renewable Energy” *Texas State Energy Conservation Office.* www.infinitepower.org/lessonplans.htm.

Wind Power Basics

HIGHLIGHTS

- Wind power is one of the oldest renewable technologies
- As wind speed doubles, power generation capability increases eightfold
- Higher is better: hilltops and tall towers lead to greater energy production
- Unlike fossil fuels, wind power cannot be depleted and produces no pollution



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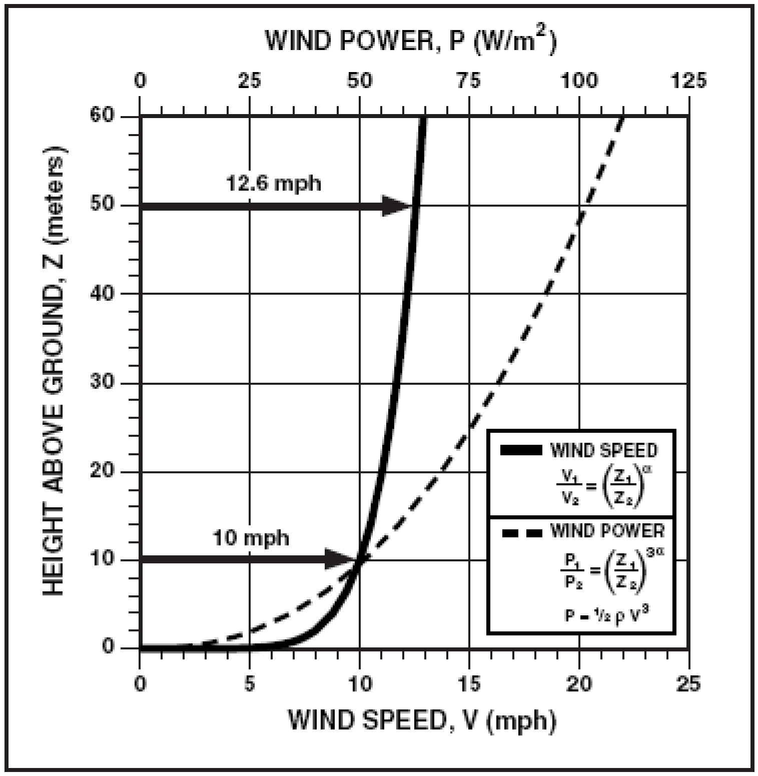
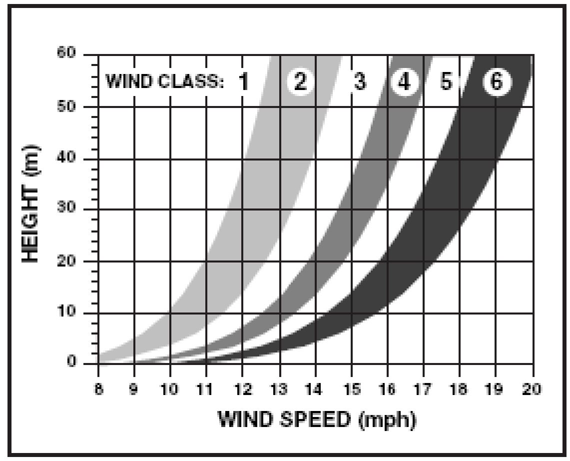


Typical wind shear profile *Speed and power available in the wind increases with increasing elevation. The relationship is commonly referred to as the one seventh power law (a=1/7)*

One easy way to access higher wind speeds is simply to go up. Winds high above the ground are stronger than winds near the ground. On average, a five-fold increase in elevation, say raising the height of the wind machine from 10 feet to 50 feet, will result in twice as much available wind power. That's why wind turbines are perched on tall towers and are often located on mountains or hilltops.

Given the need for strong winds, finding the best sites for commercial wind farms is critical. The location of power plants fueled by wind must be near existing power lines and in the windiest sites available. To compete head-to-head with fossil fuel generating technologies, wind turbines are best located in areas where wind speeds are 16-20 mph at 50 meters (m) height. Wind farms are located in the most windy areas and close to utility power lines. In Texas, the best locales are found in West Texas and the Texas Panhandle.

Air temperature is also an important factor in wind power generation. Cold air is more dense than hot air. Thus, wind turbines are able to generate about 5% more power at any given wind speed in the winter than they are during the hot days of summer.



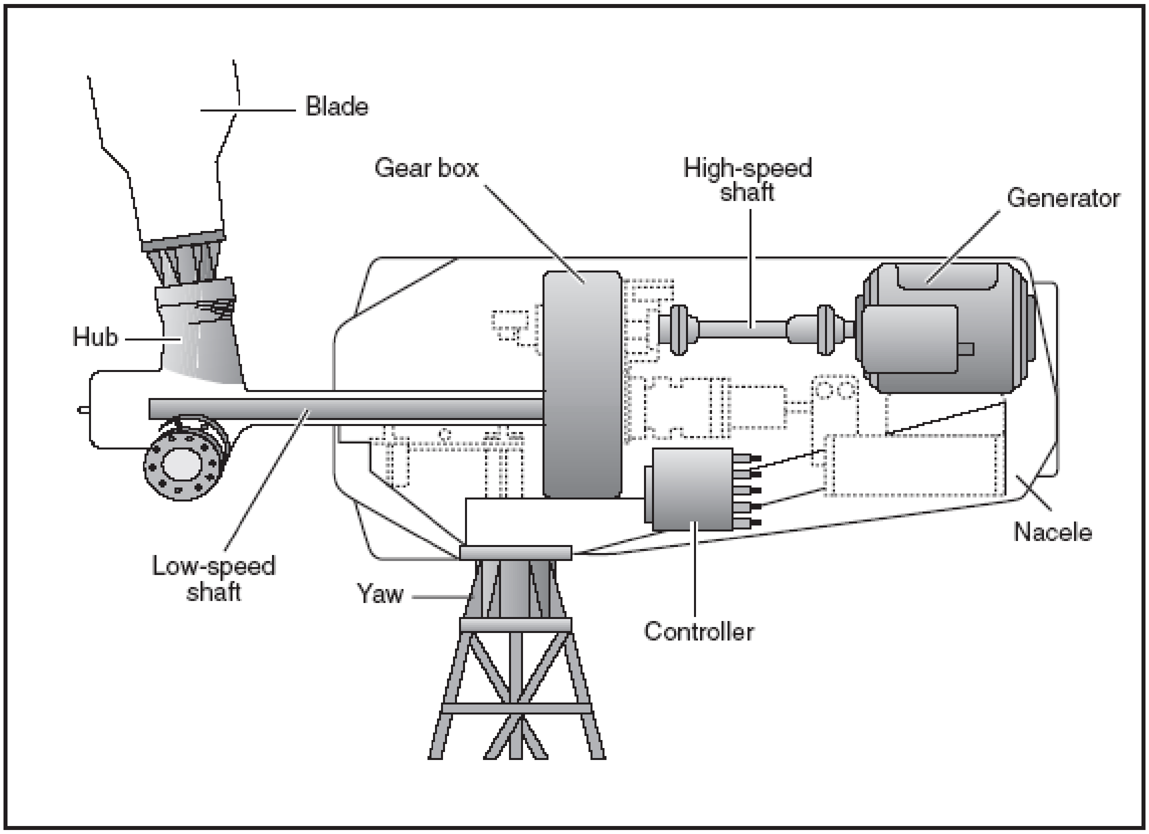
Wind power depends on elevation and wind speed *Wind Class is a relative scale used to characterize wind potential of any location. Wind Class of 3 and above are generally regarded as being suitable for commercial wind farm development.*

MAKING WATTS FROM WIND

The blades on a wind turbine are similar to the propeller blades on an airplane. The rotor blades generate lift from the passing wind, causing them to rotate the hub of the turbine. The rotating action of the hub then turns a generator, which creates electricity. A gearbox is generally necessary to optimize the power output from the machine. That power is then either fed into the electric grid or stored in batteries for use on-site.

While wind speed is important, so is the size of the rotor. On a turbine, the power available to the blades is proportional to the square of the diameter of the rotor. In other words, simply by making the turbine blades twice as long and beefing up the generator, you increase the power producing capability of the turbine by a factor of four.

Modern wind turbines come in two varieties: horizontal axis and vertical axis. Horizontal axis turbines have blades that spin on an axis that is parallel to the ground. These systems often look like the propeller on an airplane. Vertical axis systems have blades that spin on a vertical axis giving them an appearance somewhat like giant egg beaters.



Electricity generating wind turbine *The major components of this device are the blades, shaft, gearbox and generator. On large machines, additional controllers and drive motors ensure that the machine is positioned for optimal capture of the wind.*

Although large utilities are getting the most attention for their move into wind power, rural residents in all 50 states and dozens of foreign countries have quietly been installing small-scale wind generation systems. These systems can be obtained for as little as $1,000 and are perfect compliments to photovoltaic systems. Several vendors sell readymade towers and turbines that are easily installed.

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